DTU Library

Environmental Radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included. 1985

Aarkrog, A.; Boelskifte, S.; Buch, E.; Christensen, G.C.; Dahlgaard, H.; Hallstadius, L.; Hansen, H.; Holm, E.; Rioseco, J.

Publication date:
1987

Document Version
Publisher's PDF, also known as Version of record

RISØ

Risø-R-541

Environmental Radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included. 1985

A. Aarkrog, S. Boelskifte, E. Buch, G. C. Christensen, H. Dahlgaard, L. Hallstadius, H. Hansen, E. Holm, and J. Rioseco

Risø National Laboratory, DK-4000 Roskilde, Denmark
June 1987

Risø-R-541

ENVIRONMENTAL RADIOACTIVITY IN THE NORTH ATLANTIC REGION. THE FAROE ISLANDS AND GREENLAND INCLUDED. 1985

A. Aarkrog, S. Boelskifte, E. Buch°, G. C. Christensen*, H. Dahlgaard, L. Hallstadius**, H. Hansen, E. Holm***, and J. Rioseco**

o The Greenland Fisheries and Environmental Research Institute, Denmark

* Institute for Energy Technology, Kjeller, Norway

** University of Lund, Sweden

*** International Laboratory of Marine Radioactivity, Monaco

Abstract. Measurements of fallout radioactivity in the North Atlantic region including the Faroe Islands and Greenland are reported. Strontium-90 and cesium-137 was determined in samples of precipitation, sea water, vegetation, various foodstuffs (including milk in the Faroes) and drinking water. Estimates are given of the mean contents of ^{90}Sr and ^{137}Cs in human diet in the Faroes and Greenland in 1985. Results from samplings of surface sea water and seaweed in the English Channel, the Fram Strait and along the Norwegian and Greenland coasts are re-

(continued)

June 1987

Risø National Laboratory, DK-4000 Roskilde, Denmark

ported. Beside radiocesium and ^{90}Sr some of these samples have also been analysed for tritium, plutonium and americium. Finally technetium-99 data on seaweed and sea water samples collected in the North Atlantic region are presented.

ISBN 87-550-1342-2
ISSN 0106-2840
ISSN 0900-8098

Grafisk Service Risø 1987

CONTENTS

Page

1. GENERAL INTRODUCTION 7

2. ENVIRONMENTAL RADIOACTIVITY IN THE FAROE ISLANDS IN 1985 8
   2.1. Introduction 8
   2.2. Results and discussion 9
      2.2.1. Strontium-90 in Faroese precipitation 9
      2.2.2. Strontium-90 and Cesium-137 in Faroese grass 12
      2.2.3. Strontium-90 and Cesium-137 in Faroese milk 12
      2.2.4. Strontium-90 and Cesium-137 in Faroese terrestrial animals 19
      2.2.5. Strontium-90 and Cesium-137 in Faroese sea animals 20
      2.2.6. Strontium-90 and Tritium in Faroese drinking water.......................... 22
      2.2.7. Strontium-90 and Cesium-137 in miscellaneous Faroese samples 23
         2.2.7.1. Faroese soil (No samples) 23
         2.2.7.2. Faroese sea water 23
         2.2.7.3. Faroese sea plants 23
         2.2.7.4. Faroese vegetables 26
         2.2.7.5. Faroese bread 27
         2.2.7.6. Faroese eggs 28
      2.2.8. Humans from the Faroes 28
         2.2.8.1. Strontium-90 in human bone 28
   2.3. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the Faroese human diet in 1985 28
   2.4. Conclusion 33

APPENDIX 2A Predictions and observations of ^{90}Sr and ^{137}Cs in Faroese samples in 1985 35

3. ENVIRONMENTAL RADIOACTIVITY IN GREENLAND IN 1985 36
   3.1. Introduction 36

Page

3.2. Results and discussion 37
3.2.1. Strontium-90 in Greenland precipitation .. 37
3.2.2. Radionuclides in Greenland sea water 40
3.2.3. Strontium-90 and Cesium-137 in Greenland terrestrial animals 40
3.2.4. Strontium-90 and Cesium-137 i Greenland sea animals 42
3.2.5. Radionuclides in Greenland sea weed 44
3.2.6. Strontium-90 and Tritium in Greenland drinking water 46
3.3. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1985 48
3.4. Conclusion 53

4. MARINE ENVIRONMENTAL RADIOACTIVITY IN THE NORTH ATLANTIC REGION 54
4.1. The P/S Polarstern cruise in July 1985 to the Fram Strait 54
4.2. An estimate of the transfer factors of ^{137}Cs and ^{90}Sr from Sellafield to the East Greenland current based upon sea water samples collected off East Greenland in November 1984 61
4.3. Radioecological studies along the English Channel in 1985 64
4.4. Various samples from the northern North Atlantic 74
4.5. Studies of ^{90}Sr and ^{137}Cs in surface sea water collected off the West Greenland by the Greenland Fisheries and Environmental Research Institute 76

ACKNOWLEDGEMENTS 80

REFERENCES 81

ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J kg^{-1} (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J kg^{-1} (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 s^{-1} (= 27 pCi)
ALI: annual limit of intake (according to ICRP)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)
E: exa: 10^{18}
P: peta: 10^{15}
T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
k: kilo: 10^{3}
m: milli: 10^{-3}
µ: mikro: 10^{-6}
n: nano: 10^{-9}
p: pico: 10^{-12}
f: femto: 10^{-15}
a: atto: 10^{-18}

pro capite: per individual
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to 10^{9} kg TNT.

a^{-1}: per annum
OR: observed ratio
CF: concentration factor
µR: micro-roentgen, 10^{-6} roentgen
S.U.: pCi ^{90}Sr (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi ^{137}Cs (g K)$^{-1}$

V: vertebrae

m: male

f: female

nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~ 0.88 dpm). 1 g K ~ 756 pCi ~ 28 Bq.

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level

L.C.L.: lower control level

Δ: one standard deviation due to counting

S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$

f: degrees of freedom

s^2: variance

v^2: ratio between the variance in question and the residual variance

P: probability fractile of the distribution in question

η: coefficient of variation, relative standard deviation

anova: analysis of variance

Counting errors: given as relative standard deviation:

no indication: < 20%

A: 20-33%

B: >33%, such results are not considered significantly different from zero activity

B.D.L.: below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%)

** : significant (P > 99%)

***: highly significant (P > 99.9%)

1. GENERAL INTRODUCTION

Since 1962 we have published separate annual reports for the Environmental Radioactivity in the Faroes[1] and in Greenland[2]. The reports on and after 1983 are contained in the new series: "Environmental Radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included"[4] of which the present report is the third.

Chapter 2 in this report corresponds to the earlier report for the Faroes and Chapter 3 to the Greenland report.

In Chapter 4 we report on marine environmental radioactivity studies from other parts of the North Atlantic region and, furthermore, include sea water data from the Faroe Islands and Greenland. Chapter 4 also includes results from samplings carried out in earlier years.

Due to the burden of work after the Chernobyl accident in 1986, this report appears with several months' delay. For the same reason, it has been impossible to complete all analyses from the Thule 1984 sampling, from which the first results were presented in the 1984 report. The missing Thule data will appear in the 1986 report.

As mentioned also in the Danish report[3] our β-counters have been recalibrated for ^{90}Sr, and we have found that our ^{90}Sr data for the years 1980-1984 have been a factor of 1.225 times too high. This has been taken into account in the present report, when ^{90}Sr data from these five years are used.

2. ENVIRONMENTAL RADIOACTIVITY IN THE FAROE ISLANDS IN 1985

2.1. Introduction

2.1.1.

The fallout programme for the Faroes, which was initiated in 1962[1)] in close co-operation with the National Health Service and the chief physician of the Faroes, was continued in 1985. Samples of human bone were obtained in 1985 from Dronning Alexandrine's Hospital in Thorshavn.

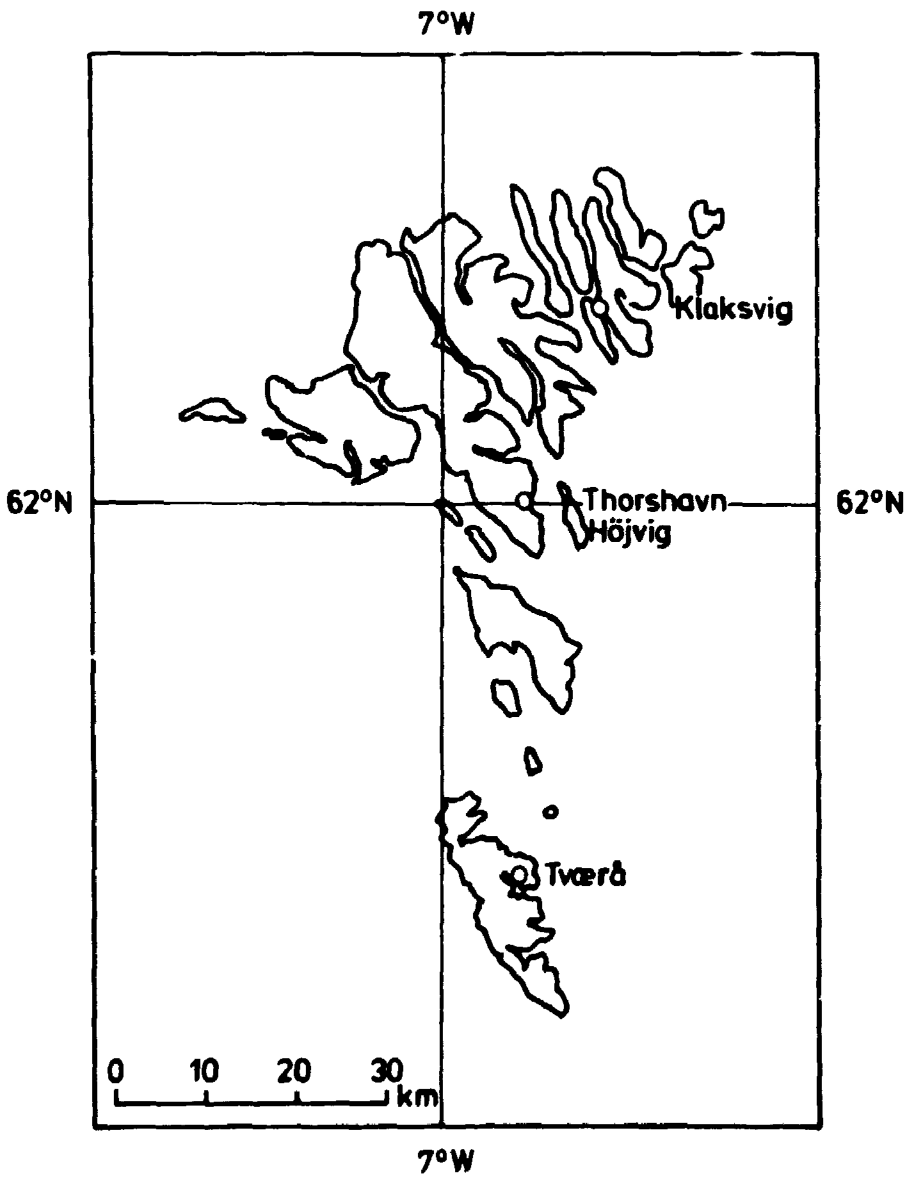


Fig. 2.1. The Faroe Islands.

2.1.2.

The present report will not repeat information concerning sample collection and analysis already given in Risø Reports Nos. 64, 86, 108, 131, 155, 181, 202, 221, 246, 266, 292, 306, 324, 346, 361, 387, 404, 422, 448, 470, 488, 510 and 528[1,4].

2.1.3.

The estimated mean diet of the Faroese as used in this report is still based on the estimate given by the late Professor E. Hoff-Jørgensen, Ph.D., in 1962.

2.1.4.

The present investigation was carried out together with corresponding examinations of fallout levels in Denmark and Greenland, described in Risø Report No. 540[3] and in Chapter 3 of this report, respectively.

2.2. Results and discussion

2.2.1. Strontium-90 in Faroese precipitation

Table 2.1 shows the ^{90}Sr content in precipitation collected at Højvig (near Thorshavn) and Klaksvig in 1985. The amount of fallout at Højvig was a factor of 2 greater than that found at Klaksvig, although the precipitation at Højvig was only 40% of that observed at Klaksvig.

The ^{90}Sr fallout in 1985 was approximately half of that in 1984. In Denmark the 1985 levels were 0.8 times the 1984 levels[2].

Table 2.2.1.1. Strontium-90 in precipitation in the Faroes in 1985 (sampling area = 0.02 m^2)

	Höjvig		Klaksvig	
	Bq m^{-3}	Bq m^{-2}	Bq m^{-3}	Bq m^{-2}
Jan-April	1.73 A	0.27 A	0.41 B	0.22 B
May-June	0.31 B	0.02 B	1.21 B	0.23 B
July-Aug	1.27 B	0.22 B	0.40 B	0.14 B
Sept-Dec	1.27 A	0.47 A	B.D.L.	B.D.L.
1985	1.36	Σ 0.98 Σ_m 0.767	0.30	Σ 0.59 Σ_m 1.961

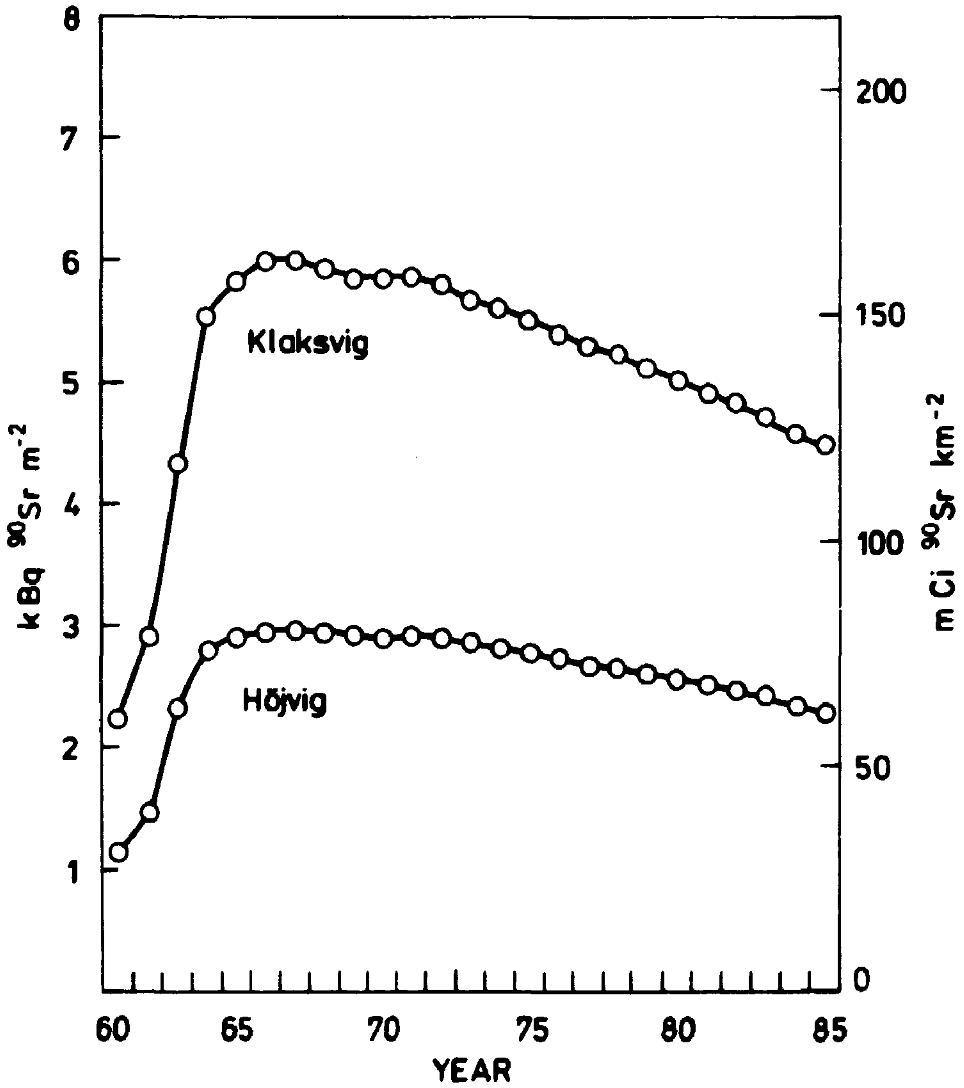


Fig. 2.2.1. Accumulated ^{90}Sr at Klaksvig and Højvig calculated from precipitation measurements since 1962. The accumulated fallout by 1962 was estimated from the Danish fallout data (cf. Risø Report No. 527[3]), Appendix D) and from the ratio between the ^{90}Sr fallout at the Faroese stations and the fallout in Denmark in the period 1962-1985 (cf. Table 2.2.1.2).

Table 2.2.1.2. Fallout rates and accumulated fallout (Bq ^{90}Sr m^{-2}) in the Faroes 1950-1985

	Höjvig		Klaksvig	
	d_i	$A_{i(29)}$	d_i	$A_{i(29)}$
1950	1.08	1.06	2.15	2.16
1951	5.21	6.12	10.34	12.14
1952	10.21	15.94	20.27	31.64
1953	25.78	40.74	51.18	80.87
1954	98.02	135.48	194.58	268.94
1955	128.96	258.20	256.00	512.54
1956	159.90	408.22	317.41	810.34
1957	159.90	554.70	317.41	1101.12
1958	221.82	758.18	440.34	1505.05
1959	314.64	1047.48	624.58	2079.33
1960	58.78	1080.14	116.69	2144.16
1961	76.36	1129.19	151.59	2241.52
1962	383.01	1476.48	760.31	2930.93
1963	913.00	2333.05	1503.00	4329.21
1964	544.00	2809.10	1363.00	5557.77
1965	181.00	2919.48	436.00	5852.21
1966	112.00	2959.88	289.00	5996.17
1967	94.70	2982.44	182.00	6032.25
1968	44.00	2954.96	55.50	5943.97
1969	41.10	2925.30	65.10	5867.15
1970	53.60	2908.54	141.00	5866.25
1971	101.00	2938.46	156.00	5880.02
1972	34.40	2902.65	55.10	5794.94
1973	24.20	2857.73	26.50	5683.95
1974	33.80	2823.23	58.80	5607.12
1975	34.40	2790.14	47.80	5521.36
1976	8.88	2732.91	21.60	5412.05
1977	27.40	2695.12	34.40	5317.81
1978	37.30	2667.89	47.60	5238.69
1979	13.30	2618.45	22.20	5136.64
1980	9.55	2565.93	10.29	5025.36
1981	18.37	2523.26	21.80	4927.96
1982	6.33	2469.84	3.91	4815.38
1983	2.75	2414.20	2.24	4703.84
1984	5.53	2362.58	0.87	4593.60
1985	0.98	2307.74	0.59	4485.68

1950-1961: are estimated values based upon HASL data (HASL Appendix 291, 1975) considering that the mean ratio between ^{90}Sr fallout in Denmark and New York was 0.7 in the period 1962-1974 and that the mean ratios between ^{90}Sr fallout in Höjvig and Denmark and between Klaksvig and Denmark are 1.39 and 2.76, respectively[5].

2.2.2. Strontium-90 and Cesium-137 in Faroese grass

Grass samples were collected near Thorshavn in 1985. Table 2.2.2 shows the results. The 1985 ^{137}Cs mean level in grass was 0.75 times the 1984 level. As compared with Danish grass in 1985[3] we found the ^{90}Sr level (Bq (kg Ca)$^{-1}$) in the Faroese grass to be higher by a factor of approximately 11.7 in the summer months, which is in agreement with the observations in previous years.

Table 2.2.2. Strontium-90 and Cesium-137 in grass from Thorshavn 1985

Month	Bq ^{90}Sr kg^{-1} dry	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1} dry	Bq ^{137}Cs (kg K)$^{-1}$
June	7.4*	1650	22	810
August	35*	7700	91	4000

*Calculated values assuming 1 kg dry grass contains 4.5 g Ca[5].

2.2.3. Strontium-90 and Cesium-137 in Faroese milk

As previously[1], weekly samples of fresh milk were obtained from Thorshavn, Klaksvig, and Tværå. Strontium-90 and ^{137}Cs were determined in bulked monthly samples.

Tables 2.2.3.1 and 2.2.3.2 show the results and Tables 2.2.3.3, 2.2.3.4 and 2.2.3.5 the analysis of variance of the Bq ^{90}Sr (kg Ca)$^{-1}$, Bq ^{137}Cs (kg K)$^{-1}$, and Bq ^{137}Cs m^{-3} figures, respectively. As also observed earlier, the variation between locations was significant for ^{137}Cs and probably also for ^{90}Sr. The highest levels were found in the milk from Tværå and Klaksvig, and the lowest in Thorshavn milk.

Figure 2.2.3.1 shows the quarterly Bq ^{90}Sr (kg Ca)$^{-1}$ values and Fig. 2.2.3.2 the quarterly Bq ^{137}Cs m^{-3} levels since 1962. The annual mean values for 1985 were 90 Bq ^{90}Sr (kg Ca)$^{-1}$ (2.4 S.U.) and 2400 Bq ^{137}Cs m^{-3} (65 pCi ^{137}Cs l^{-1}), i.e. the ^{90}Sr levels in 1985 were 69% of the 1984 concentration, while the ^{137}Cs levels were approximately 59% of the 1984 mean levels. In Danish milk the ^{90}Sr concentration in 1985 was nearly 91% of the 1984 level, and the ^{137}Cs 1985 level was also nearly 90%.

The annual mean values of the ratio: Bq ^{137}Cs (kg K)$^{-1}$/Bq ^{90}Sr (kg Ca)$^{-1}$ in Faroese milk are shown in Fig. 2.2.3.3. The annual mean ratio in 1985 for the three locations was 15.6.

Figure 2.2.3.4 shows a comparison between the ^{90}Sr and ^{137}Cs levels in Faroese- and Danish-produced milk. It is evident that indirect contamination plays an important role for the ^{137}Cs levels in the Faroes, because the ratio between ^{137}Cs in Faroese and Danish milk increases when the fallout rate decreases. The ratios between the ^{90}Sr levels in Faroese and Danisk milk have shown a slight tendency to decrease through the years.

Table 2.2.3.1. Strontium-90 in milk from the Faroes in 1985 (Bq ^{90}Sr (kg Ca)$^{-1}$)

	Thorshavn	Klaksvig	Tværå	Mean
Jan	78	160	91	110
Feb	81	89±0	101	90
March	70	108	95	91
April	70	98	126	98
May	75	95	89	86
June	74	56	105±3	78
July	65±2	101	153	106
Aug	68	80	106	85
Sept	75	76	154	102
Oct	(70)	73	98	80
Nov	66	82	85	78
Dec	67	66	92	75
Mean	72	90	108	90

The error term is 1 S.E. of determinations. Figure in bracket was estimated from neighbouring values.

Table 2.2.3.2. Cesium-137 in milk from the Faroes in 1985

	Thorshavn		Klaksvig		Tværå		Mean	
Month	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs $(kg\ K)^{-1}$
Jan	1210	840	5600	3300	3000	1770	3300	1970
Feb	1440	960	2800	1590	2800	1730	2300	1430
March	1130	760	4200	2200	3100	1940	2800	1630
April	1150	720	3100	1680	2900	1900	2400	1430
May	1150	780	2200	1200	2800	1710	2100	1230
June	1270	800	2000	1080	2800	1860	2000	1250
July	1550	900	1750	1130	4700	2900	2700	1640
Aug	1790	1270	1750	970	5000	3200	2800	1810
Sept	1650	1140	1980	1110	4900	3000	2800	1750
Oct	1280	780	1730	1110	3300	1810	2100	1230
Nov	580	360	1770	990	2800	1690	1720	1010
Dec	870	580	1580	900	2300	1450	1580	980
Mean	1260	820	2500	1440	3400	2100	2400	1450

Table 2.2.3.3. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in Faroese milk in 1985 (from Table 2.2.3.1)

Variation	SSD	f	s^2	v^2	P
Between months	0.397	11	0.036	0.838	-
Between locations	1.083	2	0.541	12.574	> 99.9%
Month × loc.	0.904	21	0.043	29.085	> 95%
Remainder	0.003	2	0.001		

Table 2.2.3.4. Analysis of variance of ln Bq ^{137}Cs (kg K)$^{-1}$ in Faroese milk in 1985 (from Table 2.2.3.2)

Variation	SSD	f	s^2	v^2	P
Between months	1.519	11	0.138	1.523	-
Between locations	5.584	2	2.792	30.806	> 99.95%
Remainder	1.994	22	0.091		

Table 2.2.3.5. Analysis of variance of ln Bq ^{137}Cs m^{-3} in Faroese milk in 1985 (from Table 2.2.3.2)

Variation	SSD	f	s^2	v^2	P
Between months	1.376	11	0.125	1.314	-
Between locations	6.631	2	3.315	34.820	> 99.95%
Remainder	2.095	22	0.095		

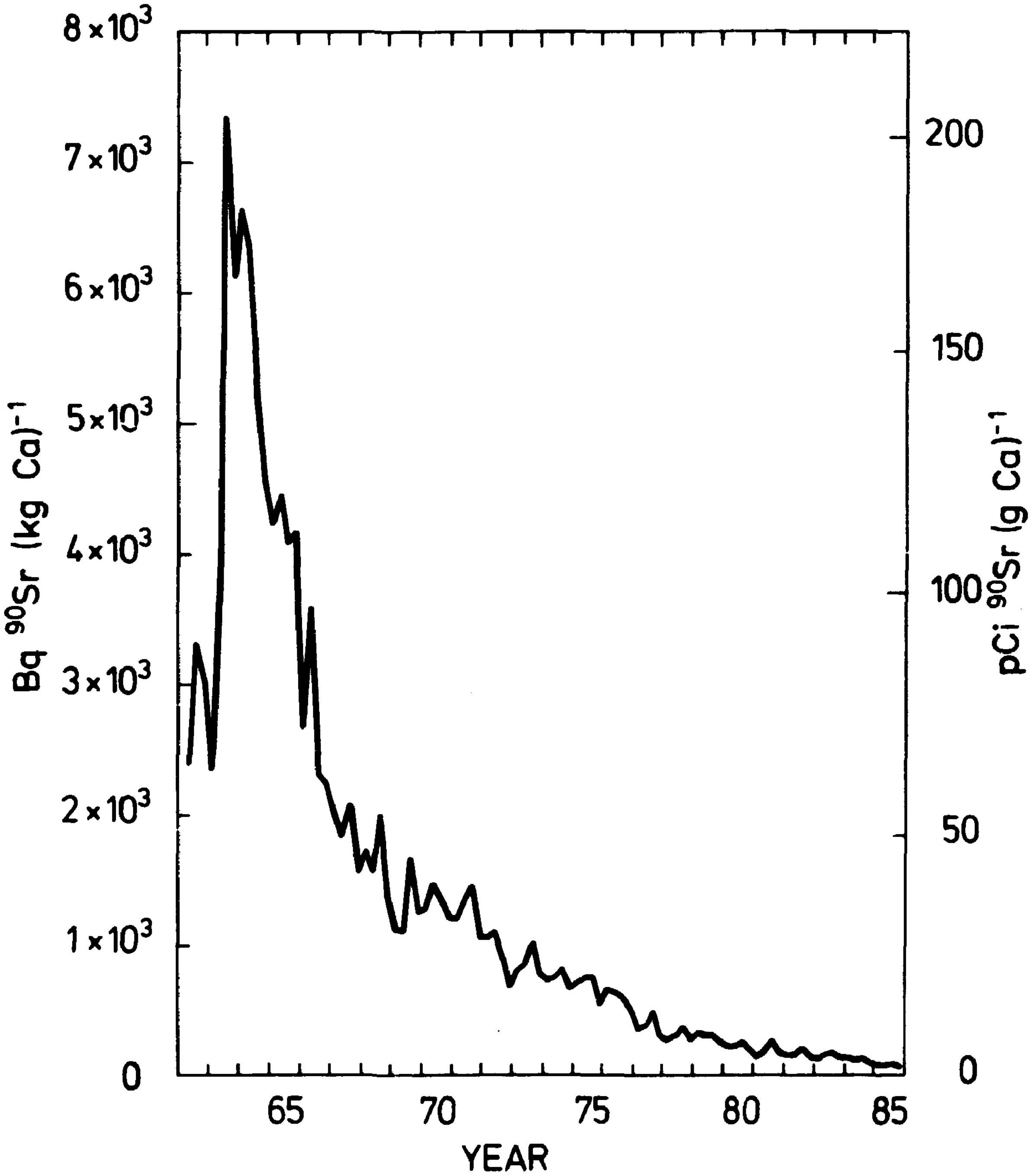


Fig. 2.2.3.1. Strontium-90 in Faroese milk, 1962-1985.

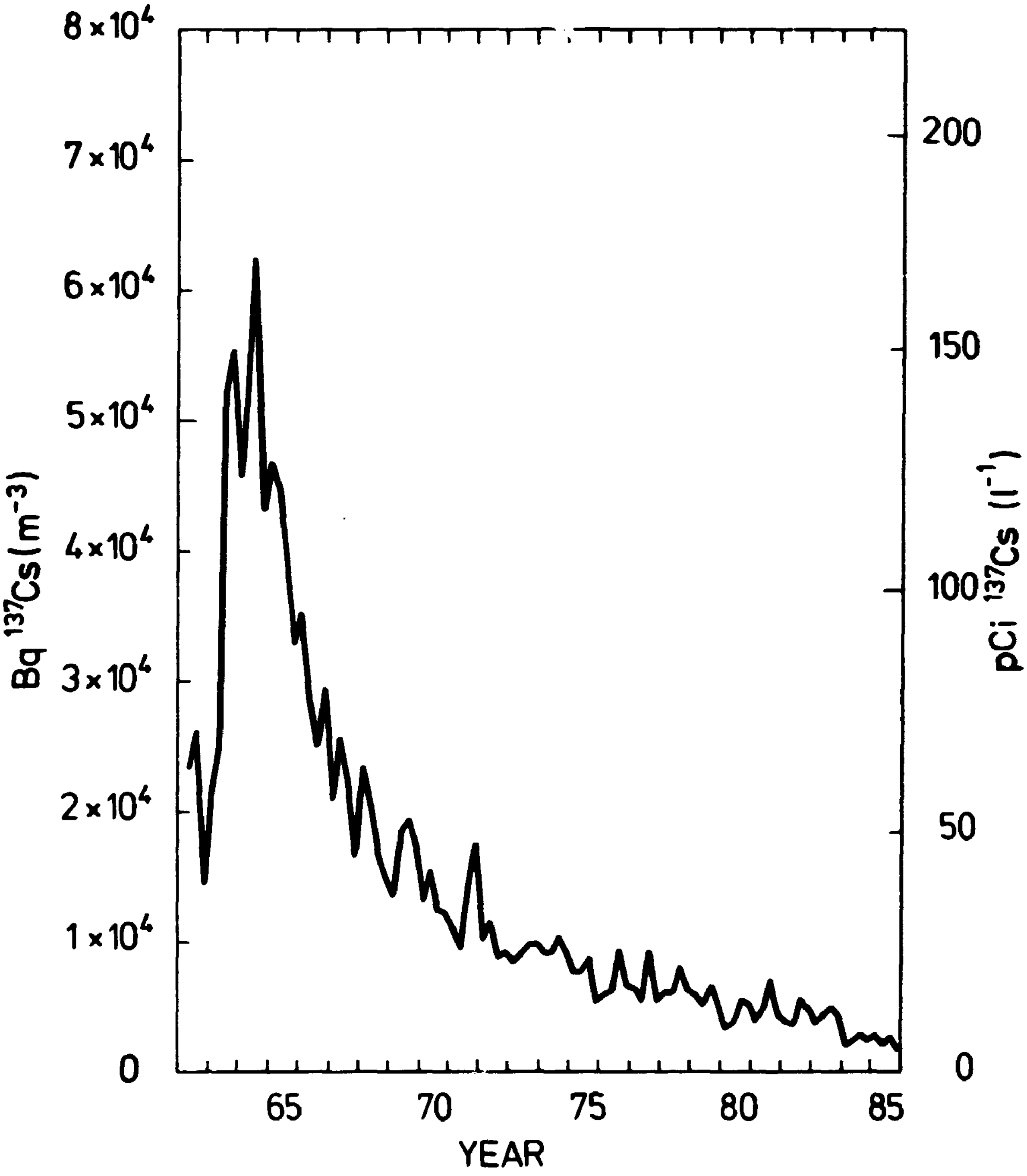


Fig. 2.2.3.2. Cesium-137 in Faroese milk, 1962-1985.

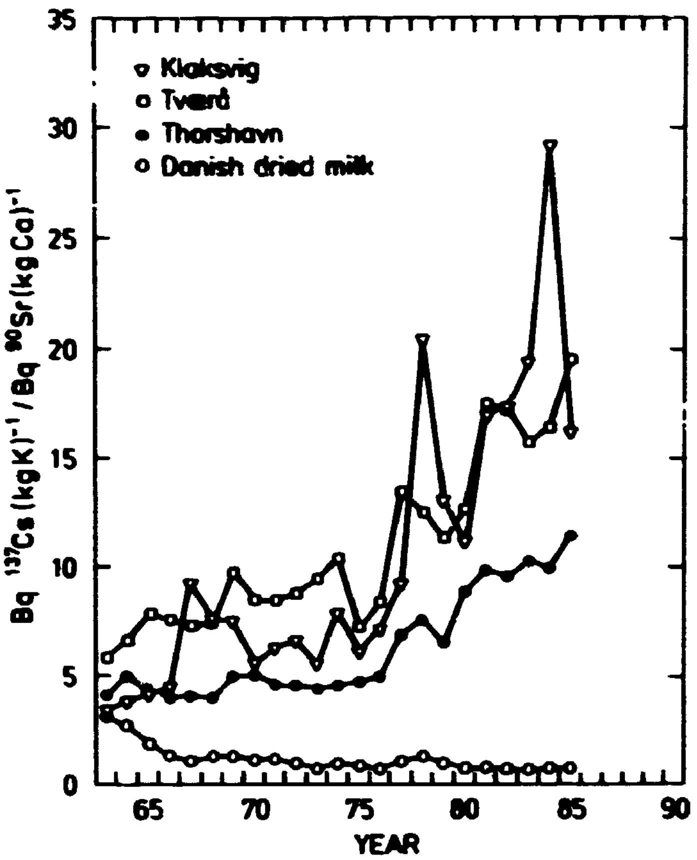


Fig. 2.2.3.3. $\frac{\text{M.U.}}{\text{S.U.}}$ ratios in Faroese and Danish milk, 1963-1985.

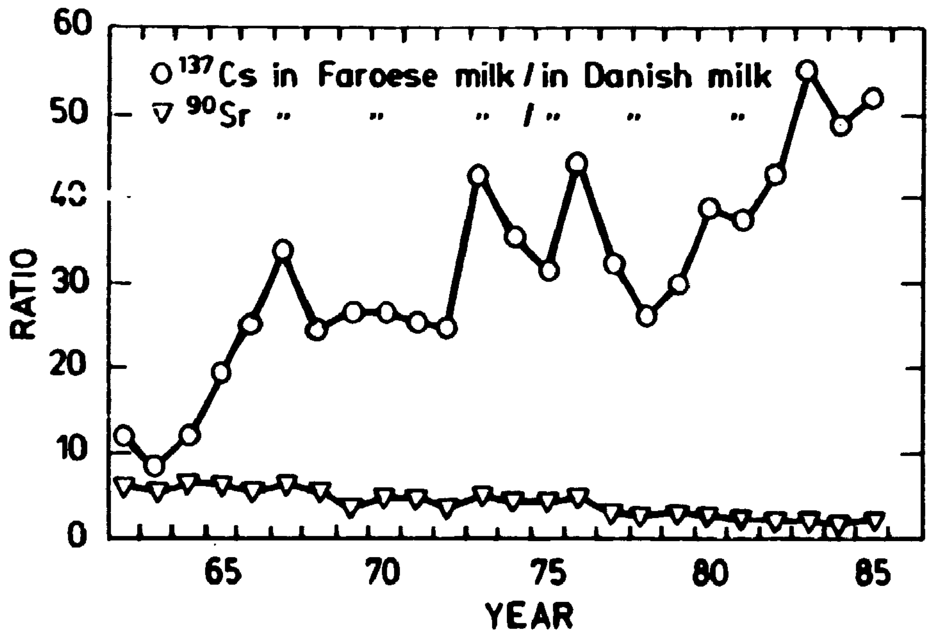


Fig. 2.2.3.4. A comparison between Faroese and Danish milk levels, 1962-1985.

2.2.4. Strontium-90 and Cesium-137 in Faroese terrestrial animals

The mean concentration in lamb meat was 22.5 Bq ^{137}Cs kg^{-1} in 1985. The ^{90}Sr mean level in bone was 1300 Bq ^{90}Sr $(kg\ Ca)^{-1}$ and in meat we found 0.093 Bq ^{90}Sr kg^{-1}. As it appears from Figs. 2.2.4.1 and 2.2.4.2 the 1985 concentrations followed the decreasing trend seen in the previous years.

A sample of puffins contained 0.21 Bq ^{137}Cs kg^{-1} meat. Strontium-90 was below the detection limit.

Table 2.2.4. Strontium-90 and Cesium-137 in lamb collected in the Faroes in November 1985

Location	Sample type	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
Thorshavn	Meat	0.220	940 (1000)	7.0	1640
Tvarå	Meat	0.059	970 (1570)	23.0	8100
- " -	Meat	0.058	800 (1870)	29.1	8300
Klaksvig	Meat	0.033	610 (740)	31.0	8000

Bone levels are shown in brackets.

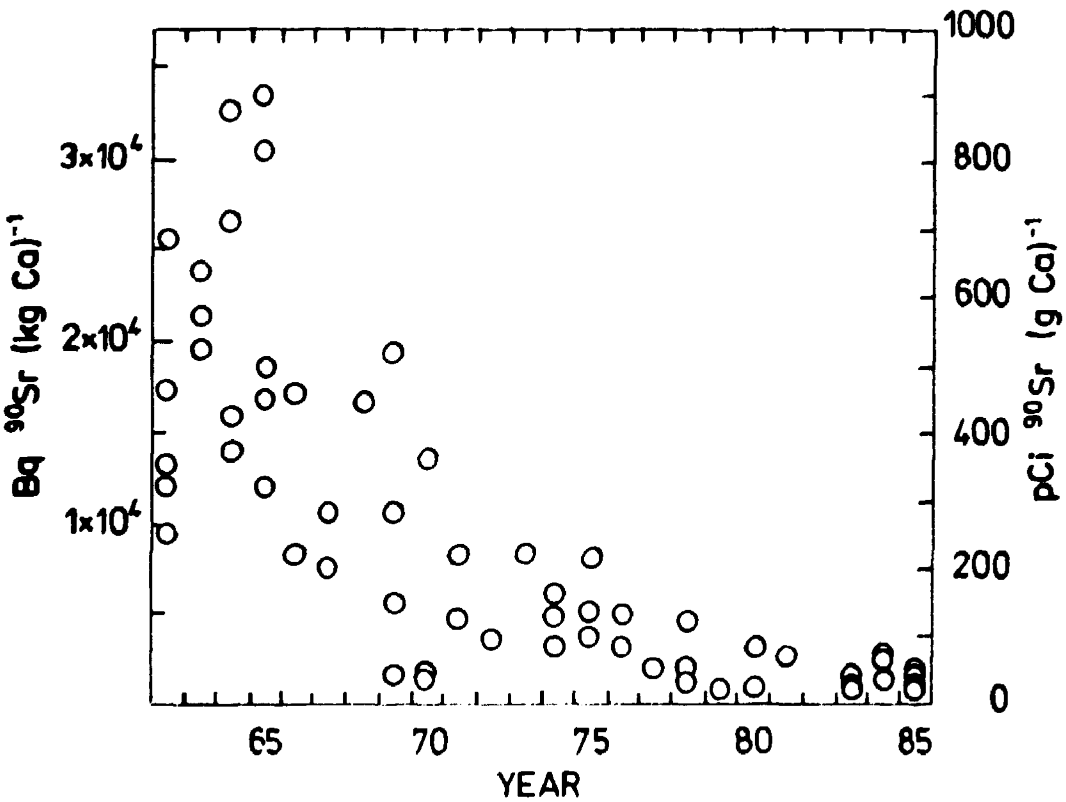


Fig. 2.2.4.1. Strontium-90 (Bq (kg Ca)$^{-1}$)) in lamb bone collected in the Faroes, 1962-1985.

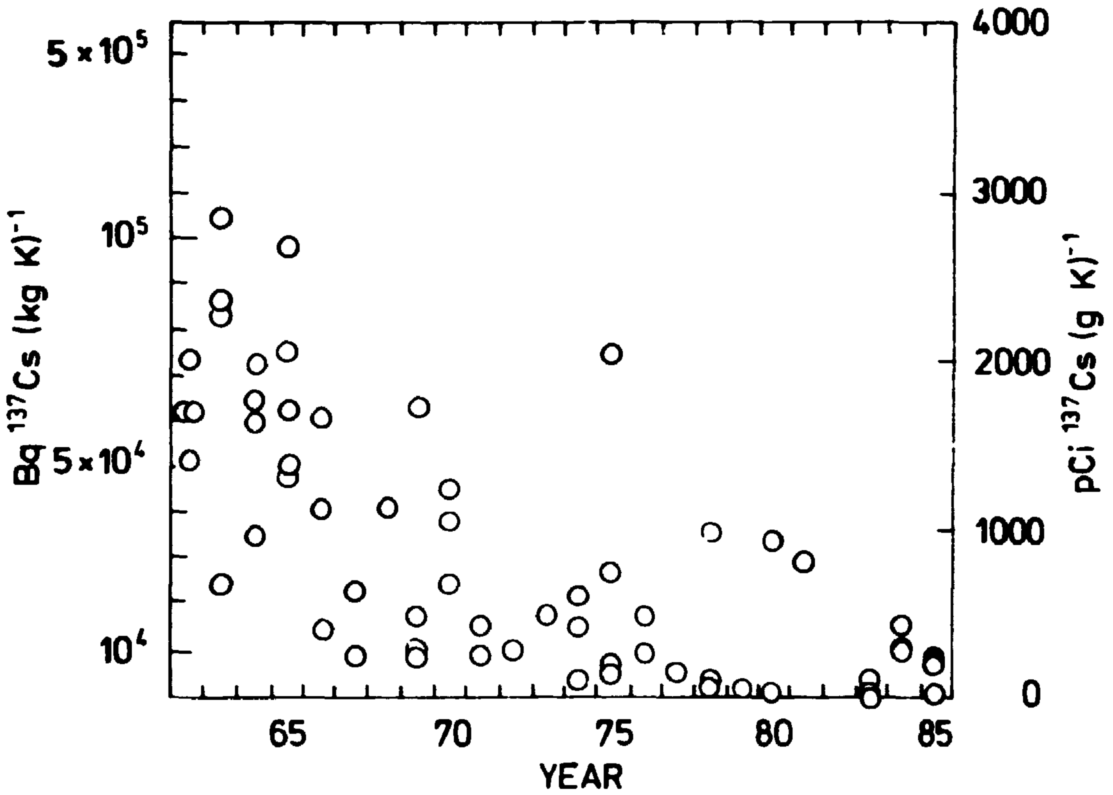


Fig. 2.2.4.2. Cesium-137 (Bq (kg K)$^{-1}$) in lamb meat collected in the Faroes, 1962-1985.

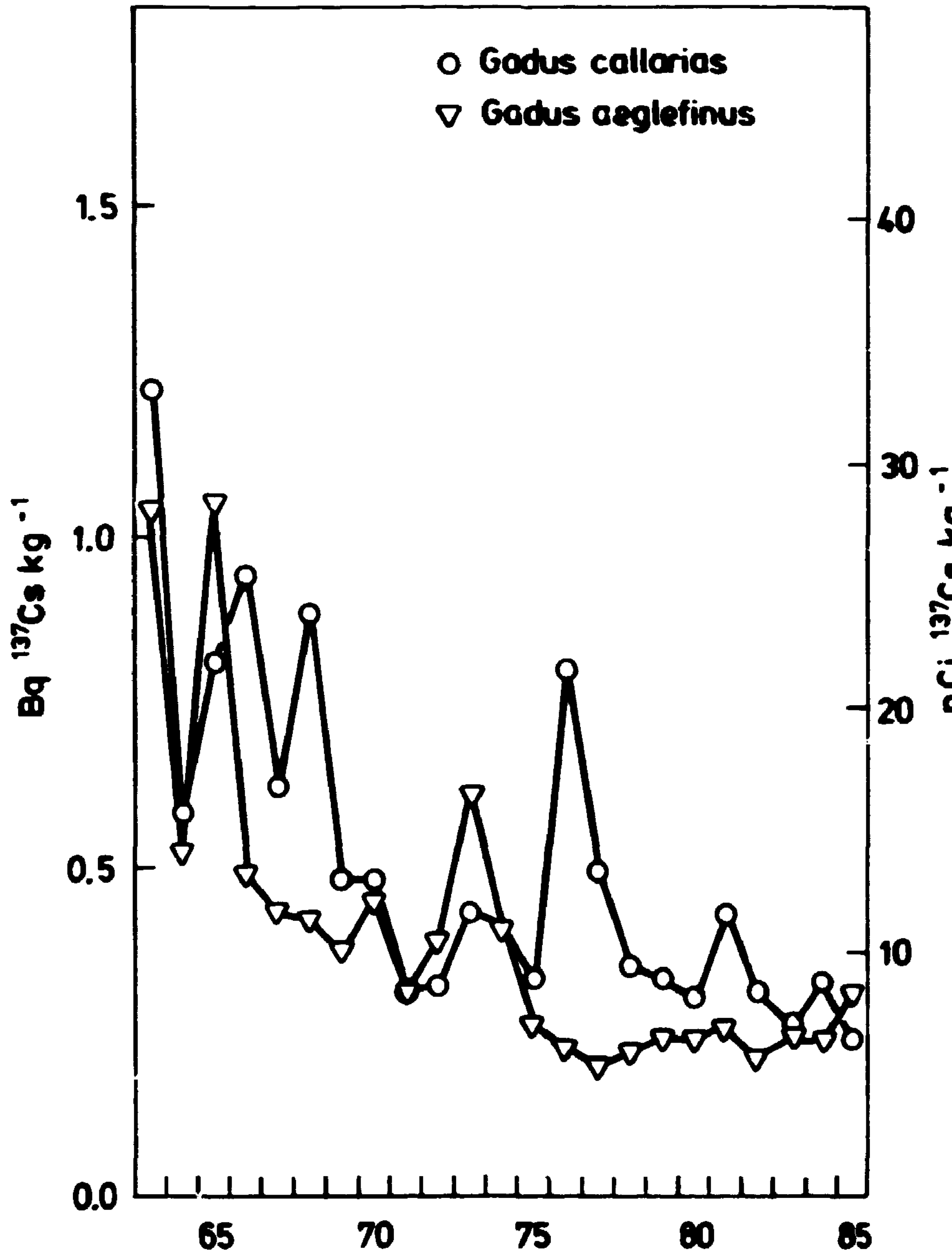
2.2.5. Strontium-90 and Cesium-137 in Faroese sea animals

Table 2.2.5.1 shows the ^{137}Cs levels in fish collected in 1985 in the Faroes. The mean levels in Gadus aeglefinus and Gadus callarias were 0.29 Bq ^{137}Cs kg^{-1} and 0.008 Bq ^{90}Sr kg^{-1}.

Whale meat from August 1985 contained 0.046 (B) Bq ^{90}Sr kg^{-1} and 0.24 (A) Bq ^{137}Cs kg^{-1} (101 (A) Bq ^{137}Cs (kg K)$^{-1}$).

Table 2.2.5.1. Strontium-90 and Cesium-137 in fish flesh from the Faroes in 1985

Sampling month	Species	Sample type	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
March	Gadus callarias	Cod flesh	0.005 B	68 B	0.30	72
June	- " -	- " -			0.28	67
Sept	- " -	- " -	0.005 B	59 B	0.29	73
Dec	- " -	- " -			0.25	63
June	Gadus aeglefinus	Haddock flesh			0.40	87
Sept	- " -	- " -	0.013 B	210 B	0.21	48
Dec	- " -	- " -			0.32	79



<u>Fig. 2.2.5.1.</u> **Cesium-137 levels in meat of cod (Gadus callarias) and Haddock (Gadus aeglefinus) collected in the Faroes, 1962-1985.**

2.2.6. Strontium-90 and Tritium in Faroese drinking water

Drinking-water samples were collected as previously but the samples were combined before the analysis as shown in Table 2.2.6.1. As in previous years, drinking water from Thorshavn contained more ^{90}Sr than that from Klaksvig and Tværå (cf. the explanation in Risø Report No. 181[1]). The mean level in 1985 was 2.5 Bq ^{90}Sr m^{-3} (0.068 pCi l^{-1}), i.e. lower than in 1985.

Figure 2.2.6.1 shows the annual mean levels of ^{90}Sr in drinking water from the three locations since 1962.

Table 2.2.6.1. Strontium-90 in drinking water from the Faroes in 1985 (Unit: Bq m^{-3})

Month	Thorshavn	Klaksvig	Tværå
Jan-June	4.4	0.74	3.2
July-Dec	3.8	1.19	1.87
1985	4.1	0.97	2.5

Table 2.2.6.2. Tritium in drinking water from the Faroes in 1985 (Unit: kBq m^{-3})

Month	Thorshavn	Klaksvig	Tværå
March	B.D.L.	B.D.L.	B.D.L.
June	1.3±0.1	B.D.L.	B.D.L.
July			1.5±0.2
Sept		B.D.L.	B.D.L.
Dec	B.D.L.	B.D.L.	B.D.L.

The error term is 1 S.E. of the mean of double determinations.

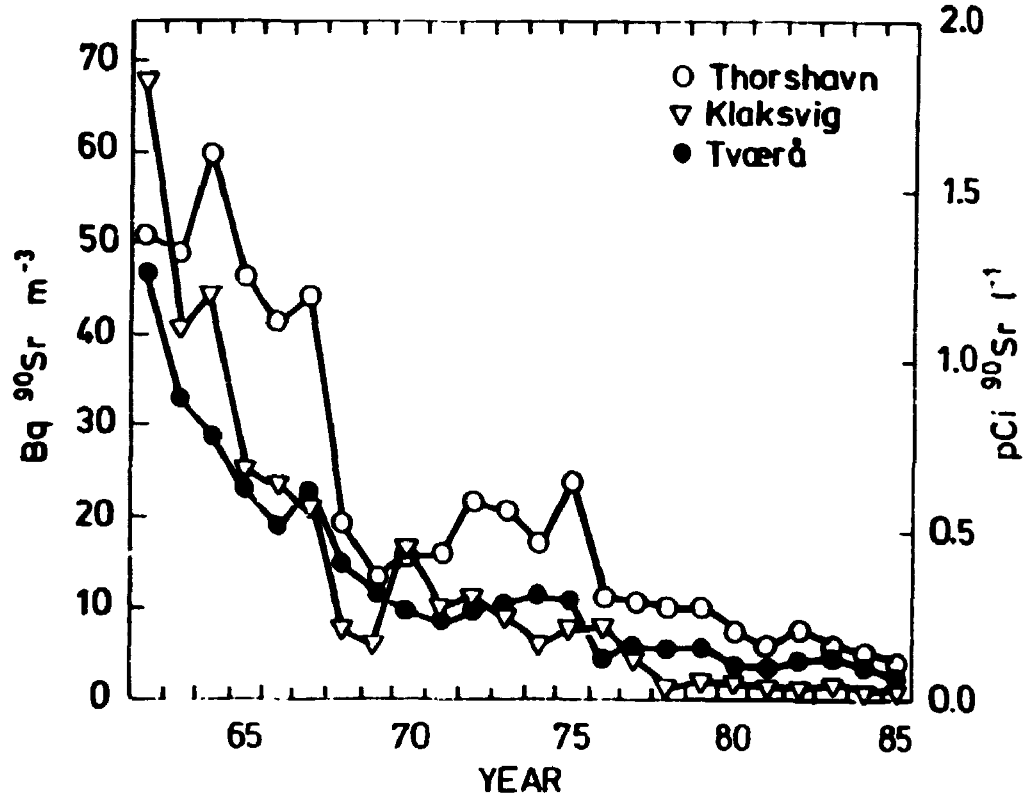


Fig. 2.2.6.1. Strontium-90 in drinking water from the Faroes, 1962-1985.

2.2.7. Strontium-90 and Cesium-137 in miscellaneous Faroese samples

2.2.7.1. Faroese soil

No samples in 1985.

2.2.7.2. Faroese sea water

Cf. Fig. 2.2.7.1 and Table 2.2.7.1.

The mean concentrations in Faroese surface sea water in 1985 decreased compared to those observed in 1984. Cesium-137 went from 3.74 Bq m^{-3} to 2.68 and ^{90}Sr from 2.08 to 1.87 Bq m^{-3}.

2.2.7.3. Faroese sea plants

Table 2.2.7.3. shows the ^{90}Sr and ^{137}Cs contents in Laminaria and Alaria esculenta in 1985.

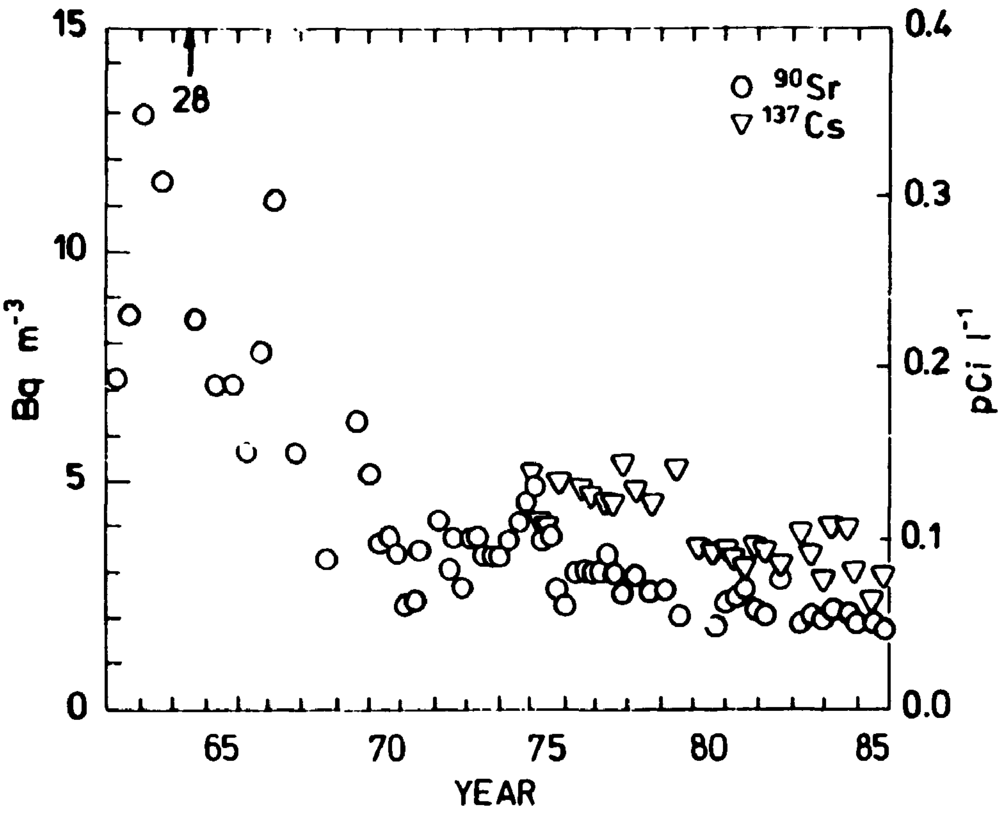


Fig. 2.2.7.2. Strontium-90 and Cesium-137 in Faroese sea water 1962-1985.

Table 2.2.7.2. Strontium-90 and Cesium-137 in Faroese sea water collected at Thorshavn in 1985 (Bq m^{-3})

Sampling month	^{90}Sr	^{137}Cs	Salinity o/oo
June	1.94	2.38	35.4
August	1.79	2.97	35.3

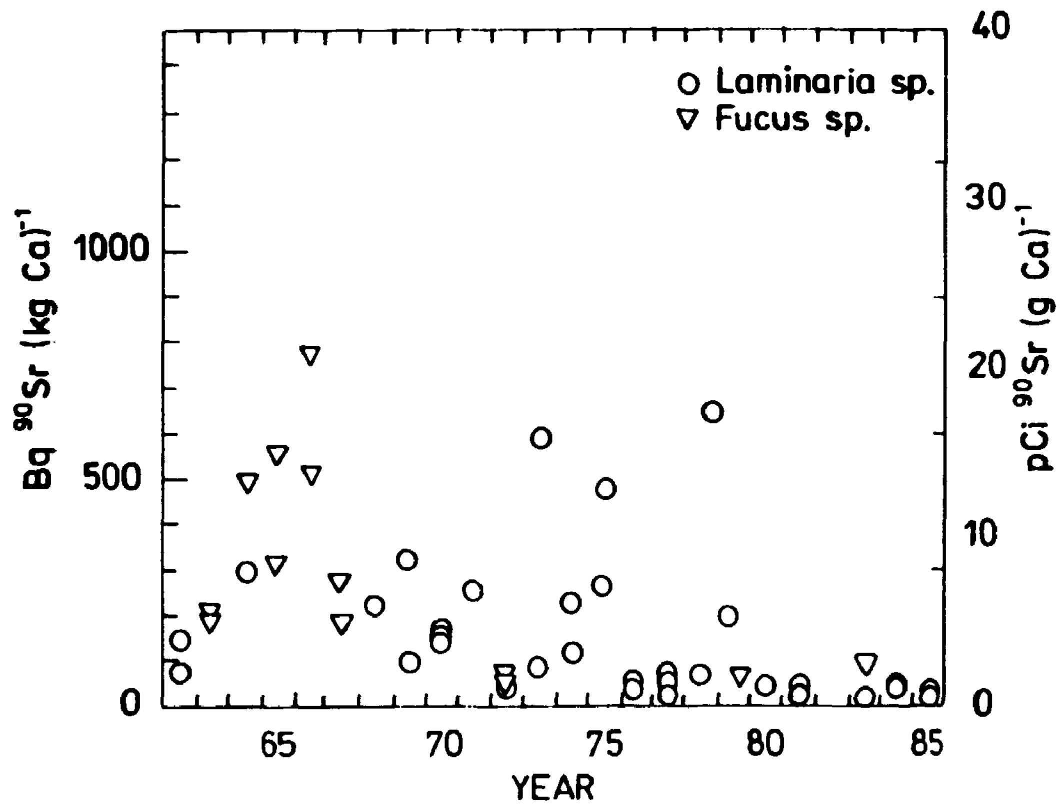


Fig. 2.2.7.3. Strontium-90 (Bq (kg Ca)$^{-1}$) in sea plants collected at Thorshavn, 1962-1985.

Table 2.2.7.3. Radionuclides in Faroese seaweed collected in 1985

Species	Date	Bq ^{90}Sr kg^{-1} dry	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1} dry	Bq ^{137}Cs (kg K)$^{-1}$
Laminaria	April	0.49	34	0.78 A	10.9 A
- " -	Sept	0.25 A	20 A	0.64	13.8
Alaria esculenta	April	0.40	32	0.23 B	4.6 B
- " -	April	-	-	0.24 B	4.2 B
- " -	Sept	0.52	39	0.34 A	7.6 A
- " -	Sept	0.48	31	0.29 B	7.2 B

2.2.7.4. Faroese vegetables

Three samples of potatoes were analysed in 1985. The mean content was 0.164 Bq ^{90}Sr kg^{-1} (4500 Bq ^{90}Sr (kg Ca)$^{-1}$) and 2.8 Bq ^{137}Cs kg^{-1} (800 Bq ^{137}Cs (kg K)$^{-1}$).

Table 2.2.7.4. Radionuclides in Faroese potatoes collected in December 1985

Location	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Thorshavn	0.065	2500	2.1	590
Klaksvig	0.33	8700	2.3	640
Tvarå	0.096	2200	4.1	1170

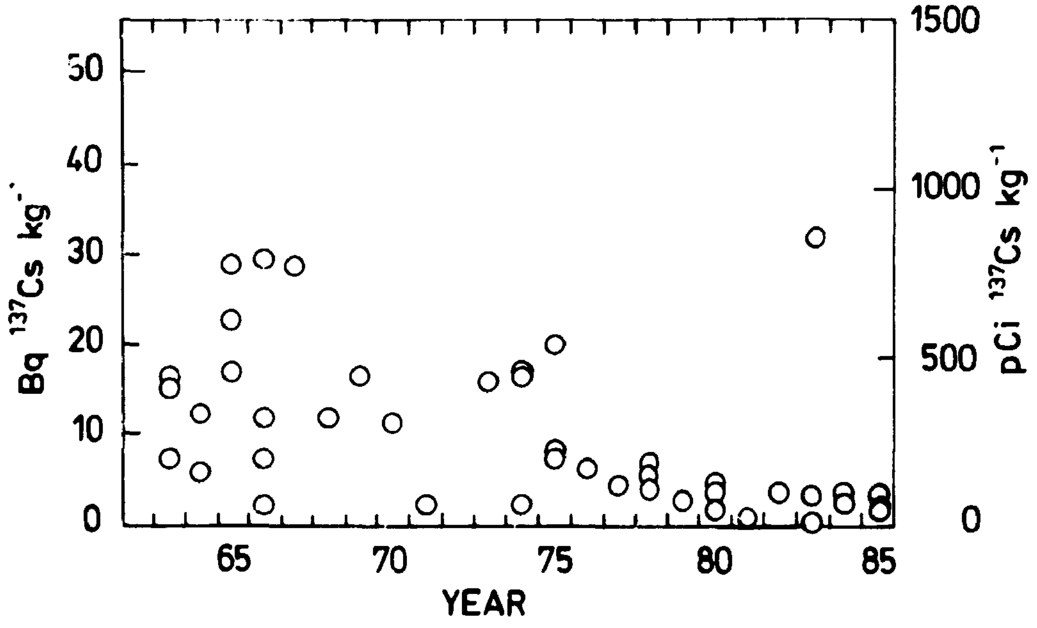


Fig. 2.2.7.4.1. Cesium-137 in Faroese potatoes, 1962-1985.

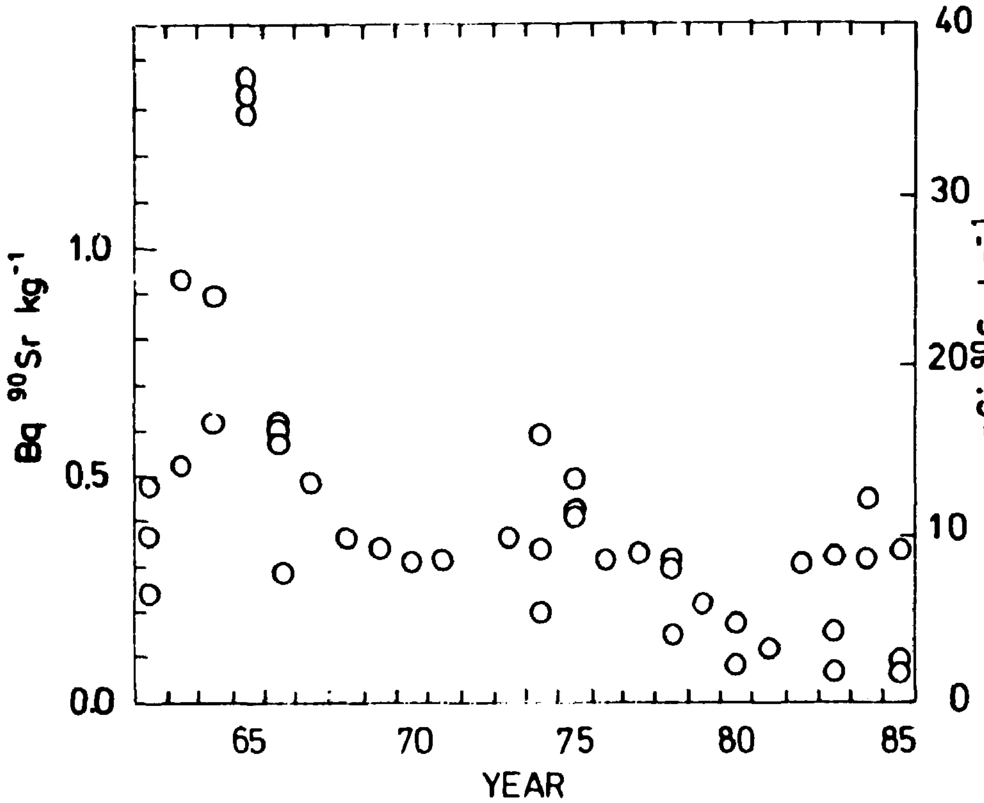


Fig. 2.2.7.4.2. Strontium-90 in Faroese potatoes, 1962-1985.

2.2.7.5. Faroese bread

Rye bread and white bread were collected at Thorshavn in June. The levels in white bread were 0.068 Bq ^{90}Sr kg^{-1} and 0.025 Bq ^{137}Cs kg^{-1}. The rye bread collected in 1985 contained 0.21 Bq ^{90}Sr kg^{-1} and 0.09 Bq ^{137}Cs kg^{-1}. The bread levels were lower than those in 1984.

The ^{137}Cs and ^{90}Sr (kg^{-1}) levels in Faroese rye bread in 1985 were somewhat lower than the corresponding Danish[3].

Table 2.2.7.5. Strontium-90 and Cesium-137 in Faroese bread in June 1985

Sort	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
White bread	0.068	35	0.025 B	20 B
Rye bread	0.21	86	0.091 A	42 A

2.2.7.6. Faroese eggs

Eggs were collected from Thorshavn in June 1985. The levels of hens eggs were 0.023 Bq ^{90}Sr kg^{-1} (39 Bq (kg Ca)$^{-1}$ and 0.061 Bq ^{137}Cs kg^{-1} (45 Bq ^{137}Cs (kg K)$^{-1}$).

2.2.8. Humans from the Faroes

2.2.8.1. Strontium-90 in human bone

In 1985 one human bone samples were obtained from Dronning Alexandrine's Hospital in Thorshavn. Table 2.2.8.1 shows the result.

Table 2.2.8.1. Strontium-90 in human bone collected in the Faroes in 1985

Age	Bone type		Sex	Bq ^{90}Sr (kg Ca)$^{-1}$
82 years	Femur	Amputation	M	26

2.3. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the Faroese human diet in 1985

2.3.1. Annual quantities

The annual quantities are still based on the estimate made by the late Professor E. Hoff-Jørgensen, Ph.D., in 1962[1)] assuming a daily pro capite intake of approximately 3000 calories (12.6 MJ).

2.3.2. Milk and cream

75% of the milk consumed in the Faroes is assumed to be of local origin, and 25% comes from Denmark. Hence the ^{90}Sr content in milk consumed in the Faroes in 1985 was 1.2×(0.75·0.090

+ 0.25×0.060) = 0.099 Bq ^{90}Sr kg^{-1}, and the ^{137}Cs content was 0.75×2.4 + 0.25×0.076 = 1.82 Bq ^{137}Cs kg^{-1} (cf. 2.2.3 and Ref. 3). 1 kg milk contains 1.2 g Ca.

2.3.3. Cheese

Nearly all cheese consumed in the Faroes is of Danish origin, and the Danish figures from ref. 3 were used: 0.51 Bq ^{90}Sr kg^{-1} and 0.055 Bq ^{137}Cs kg^{-1}.

2.3.4. Grain products

As most grain products are imported from Denmark, the Danish figures for 1985[3)] were used in the calculation of the Faroese levels. The mean daily consumption of grain products in the Faroes is, as in Denmark, 80 g rye flour, 120 g wheat flour, and 20 g grits. Hence the mean concentration of ^{90}Sr in grain products consumed in the Faroes in 1985 is 0.173 Bq ^{90}Sr kg^{-1} and 0.078 Bq ^{137}Cs kg^{-1}.

2.3.5. Potatoes

All potatoes consumed in the Faroes are assumed to be of local origin. The values from 2.2.7.4 were used, i.e. 0.164 Bq ^{90}Sr kg^{-1} and 2.8 Bq ^{137}Cs kg^{-1}.

2.3.6. Other vegetables and fruit

As the amount of vegetables and fruit grown in the Faroes is limited, the Danish figures from 1985[3)] were used. Thus the mean contents in vegetables other than potatoes were 0.24 Bq ^{90}Sr kg^{-1} and 0.052 Bq ^{137}Cs kg^{-1}, and the mean contents in fruit were 0.062 Bq ^{90}Sr kg^{-1} and 0.016 Bq ^{137}Cs kg^{-1}.

2.3.7. Meat and eggs

Meat and egg consumption in the Faroes is estimated to consist of 50% locally produced mutton (or lamb), 25% local whale meat, and 25% sea birds and eggs.

For lamb we use the mean of the samples obtained in 1985, i.e. 0.093 Bq $^{90}Sr\ kg^{-1}$ and 22.5 Bq $^{137}Cs\ kg^{-1}$. Whale meat contained 0.046 Bq $^{90}Sr\ kg^{-1}$ and 0.24 Bq $^{137}Cs\ kg^{-1}$, sea birds contained 0.21 Bq $^{137}Cs\ kg^{-1}$, and eggs (cf. 2.2.4 and 2.2.7.6): 0.023 Bq $^{90}Sr\ kg^{-1}$ and 0.061 Bq $^{137}Cs\ kg^{-1}$. Hence we estimate the mean content of ^{90}Sr in meat and eggs consumed in 1985 to be

$$0.50 \cdot 0.093 + 0.25 \cdot 0.046 + 0.25 \cdot \left(\frac{0.003^* + 0.021}{2}\right) = 0.061\ \text{Bq}\ ^{90}\text{Sr kg}^{-1}$$

(*last year's figure for sea birds)

and the ^{137}Cs content to be

$$0.50 \cdot 22.5 + 0.25 \cdot 0.24 + 0.25 \cdot \left(\frac{0.21 + 0.061}{2}\right) = 11.34\ \text{Bq}\ ^{137}\text{Cs kg}^{-1}.$$

2.3.8. Fish

All fish consumed in the Faroes is of local origin, and the mean contents in fish, obtained from subsection 2.2.5, were 0.008 Bq $^{90}Sr\ kg^{-1}$ and 0.29 Bq $^{137}Cs\ kg^{-1}$.

2.3.9. Coffee and tea

The Danish figures for 1985[3)] were used, i.e. 1.00 Bq $^{90}Sr\ kg^{-1}$ and 1.53 Bq $^{137}Cs\ kg^{-1}$.

2.3.10. Drinking water

The mean value found in Table 2.2.6.1 was used, i.e. 0.0025 Bq $^{90}Sr\ kg^{-1}$. The ^{137}Cs content was estimated to be approximately one fourth (the ratio found in New York tap water in 1964[4)]) of the ^{90}Sr content i.e. 0.0006 Bq $^{137}Cs\ kg^{-1}$.

Tables 2.3.1 and 2.3.2 show the diet estimates of ^{90}Sr and ^{137}Cs, respectively.

Table 2.3.1. Estimate of the mean content of ^{90}Sr in the human diet in the Faroe Islands in 1985

Type of food	Annual quantity in kg	Bq ^{90}Sr per kg	Total Bq ^{90}Sr	Percentage of total Bq ^{90}Sr in food
Milk and cream	146	0.099	14.45	22.4
Cheese	7.3	0.51	3.72	5.8
Grain products	80	0.173	13.84	21.5
Potatoes	91	0.164	14.92	23.1
Vegetables	20	0.24	4.80	7.5
Fruit	18	0.062	1.12	1.7
Meat and eggs	37	0.061	2.26	3.5
Fish	91	0.008	0.73	1.1
Coffee and tea	7.3	1.00	7.30	11.3
Drinking water	548	0.0025	1.37	2.1
Total			64.51	

The mean annual calcium intake is estimated to be 0.6 kg (approx. 200-250 g of creta praeparata). Hence the ratio: Bq ^{90}Sr (kg Ca)$^{-1}$ in total Faroese diet was 108 (2.9 pCi ^{90}Sr (g Ca)$^{-1}$).

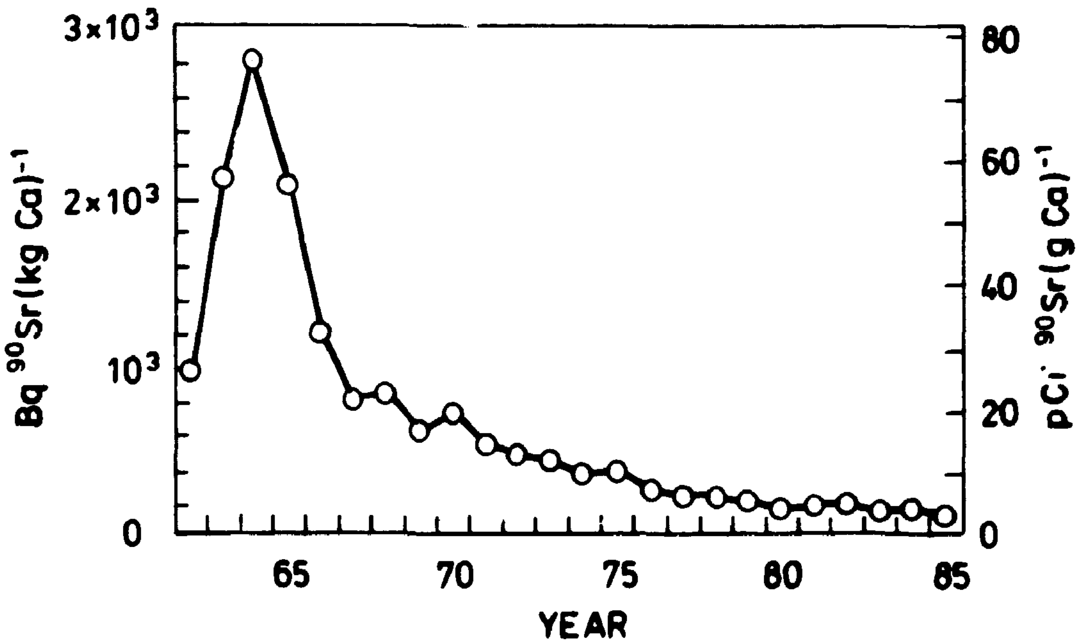


Fig. 2.3.1. Strontium-90 in Faroese diet, 1962-1985.

Table 2.3.2. Estimate of the mean content of ^{137}Cs in the human diet in the Faroe Islands in 1985

Type of food	Annual quantity in kg	Bq ^{137}Cs per kg	Total Bq ^{137}Cs	Percentage of total Bq ^{137}Cs in food
Milk and cream	146	1.82	265.7	27.0
Cheese	7.3	0.055	0.4	0
Grain products	80	0.078	6.2	0.6
Potatoes	91	2.8	254.8	25.9
Vegetables	20	0.052	1.0	0.1
Fruit	18	0.016	0.3	0
Meat and eggs	37	11.34	419.6	42.6
Fish	91	0.29	26.4	2.7
Coffee and tea	7.3	1.53	11.2	1.1
Drinking water	548	0.0006	0.3	0
Total			985.9	

The mean annual intake of potassium is estimated to be approx. 1.2 kg. Hence the ratio: Bq ^{137}Cs $(kg\ K)^{-1}$ becomes 820 (22 pCi ^{137}Cs $(g\ K)^{-1}$).

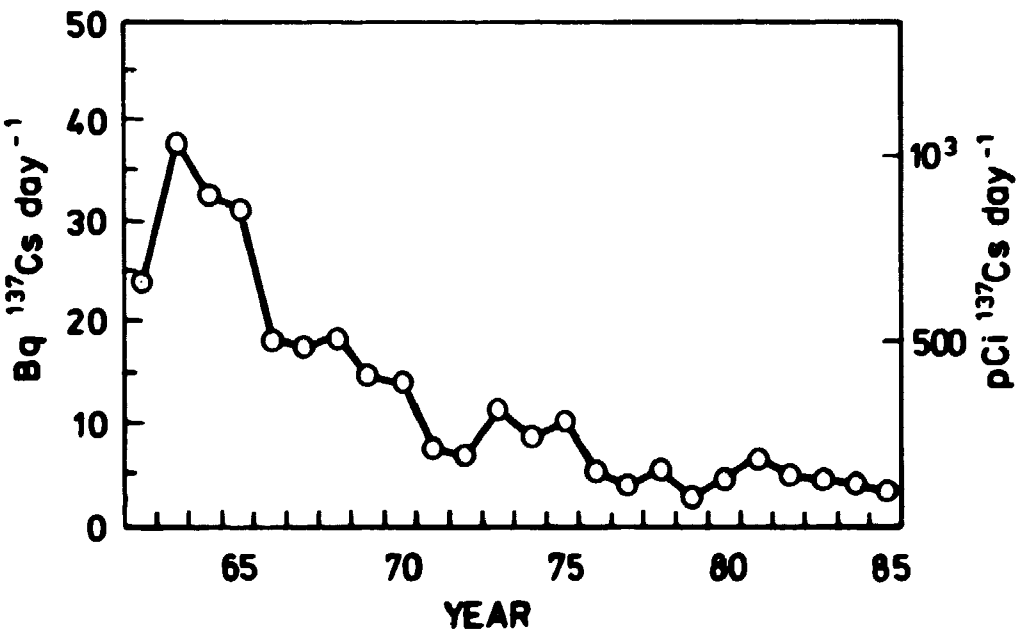


Fig. 2.3.2. Cesium-137 in Faroese diet, 1962-1985.

2.3.11. Discussion

Figures 2.3.1 and 2.3.2 show the Faroese diet levels since 1962.

The 1985 ^{90}Sr level in the total Faroese diet was 71% of the 1984 concentration, and the ^{137}Cs level was 63% of that observed in 1984.

The main contributors to the ^{90}Sr content in the Faroese diet were milk products, cereals and potatoes, which together accounted for approximately 73% of the total ^{90}Sr content in the diet in 1985. As regards ^{137}Cs, potatoes, milk products and meat (lamb) were the most important contributors. In 1985, 96% of the total ^{137}Cs content in the diet originated from these products.

The Faroese mean diet contained 1.17 times as much ^{90}Sr and approximately 12 times as much ^{137}Cs as the Danish diet in 1985[3].

As earlier[1] mentioned, the year-to-year variations in the ^{137}Cs estimates for Faroese diet are markedly influenced by the mutton and potato samples obtained for analysis.

2.4. Conclusion

2.4.1.

The ^{90}Sr fallout rate in the Faroes in 1985 was approximately 0.8 Bq ^{90}Sr m^{-2} (0.02 mCi km^{-2}). The accumulated fallout by the end of 1985 was estimated at approximately 3400 Bq ^{90}Sr m^{-2} (92 mCi km^{-2}) (the mean at Thorshavn and Klaksvig).

2.4.2.

The mean level of ^{90}Sr in Faroese milk was 90 Bq (kg Ca)$^{-1}$ (2.4 pCi (g Ca)$^{-1}$). The ^{137}Cs concentration was 2400 Bq ^{137}Cs m^{-3} (65 pCi l^{-1}).

Lamb contained 22.5 Bq ^{137}Cs kg^{-1} (610 pCi kg^{-1}) in 1985. Fish showed a mean level of 0.29 Bq ^{137}Cs kg^{-1} (7.8 pCi kg^{-1}).

The mean content of ^{90}Sr in drinking water was 2.5 Bq m^{-3} (0.07 pCi l^{-1}).

The mean daily pro capite intakes resulting from the Faroese diet in 1985 were estimated at 0.18 Bq ^{90}Sr (4.8 pCi d^{-1}) and 2.7 Bq ^{137}Cs (73 pCi d^{-1}).

2.4.3.

The mean content of ^{137}Cs in the Faroese adult was estimated at approximately 2300 Bq ^{137}Cs (kg K)$^{-1}$ (63 pCi (g K)$^{-1}$). This estimate is based on the diet estimate.

APPENDIX 2A

Predictions and observations of ^{90}Sr and ^{137}Cs in Faroese samples in 1985

The models used for the predictions shown in Table 2A were based on data collected 1962-1976[5]. If the predictions for previous years 1977-1982[1] were considered too, we conclude that the model for ^{90}Sr in milk overestimates the level and so do the model for ^{137}Cs in milk from Tvarå. The following models underestimate the concentrations: ^{90}Sr in cod fish and ^{137}Cs in milk from Klaksvig.

Table 2A. Comparison between observed and predicted ^{90}Sr and ^{137}Cs concentrations in Faroese samples collected in 1985

Sample	Unit	Observed ±1 S.E.	Number of samples	Predicted	Obs./pre. ±1 S.E.	Model in ref. 5
Drinking water, Thorshavn	Bq ^{90}Sr m^{-3}	4.1 ±0.3	2	14.4	0.28±0.02	C.1.4.1 No. 9
- " - , Klaksvig	- " -	0.97 ±0.23	2	1.6	0.61±0.14	- " - No. 10
- " - , Tvarå	- " -	2.5 ±0.7	2	3.1	0.81±0.23	- " - No. 11
Sea water	- " -	1.87 ±0.08	2	2.0	0.94±0.04	C.1.5.1 No. 3
Grass	Bq ^{90}Sr $(kg\ Ca)^{-1}$	4700 ±300	2	4900	0.96±0.61	C.2.4.1 No. 4
- " -	Bq ^{137}Cs $(kg\ K)^{-1}$	2400 ±1600	2	310	7.74±5.16	C.2.4.2 No. 3
Potatoes	Bq ^{90}Sr kg^{-1}	0.16 ±0.08	3	0.21	0.76±0.38	C.2.5.1 No. 11
- " -	Bq ^{137}Cs kg^{-1}	2.8 ±0.6	3	6.3	0.44±0.09	C.2.5.3 No. 8
Milk	Bq ^{90}Sr $(kg\ Ca)^{-1}$	90 ±3.4	12	290	0.31±0.01	C.3.3.1 No. 1
Milk Thorshavn	Bq ^{137}Cs m^{-3}	1260 ±96	12	1250	1.01±0.08	C.3.3.2 No. 7
Milk Klaksvig	- " -	2500 ±360	12	1580	1.58±0.22	- " - No. 9
Milk Tvarå	- " -	3400 ±270	12	6900	0.49±0.04	- " - No. 11
Cod fish	Bq ^{90}Sr $(kg\ Ca)^{-1}$	112 ±49	3	21	5.33±2.33	C.3.5.1 No. 3
- " -	Bq ^{137}Cs kg^{-1}	0.29 ±0.02	7	0.19	1.53±0.11	C.3.5.2 No. 2
Lamb meat	Bq ^{90}Sr $(kg\ Ca)^{-1}$	830 ±82	4	1160	0.72±0.07	C.3.4.1 No. 5
- " -	Bq ^{137}Cs $(kg\ K)^{-1}$	6500 ±1620	4	3000	2.17±0.54	C.3.4.2 No. 5
Lamb bone	Bq ^{90}Sr $(kg\ Ca)^{-1}$	1300 ±260	4	2000	0.65±0.13	C.3.4.3 No. 1
Whale	Bq ^{90}Sr kg^{-1}	0.046	1	0.013	3.54	C.3.6.1 No. 3
- " -	Bq ^{137}Cs kg^{-1}	0.24	1	0.39	0.62	C.3.6.2 No. 2

3. ENVIRONMENTAL RADIOACTIVITY IN GREENLAND IN 1985

3.1. Introduction

3.1.1.

In 1985 the sampling programme was similar to that used in previous years but for a few minor modifications.

3.1.2.

As hitherto, samples were collected through the local district physicians and the head of the telestations. However, we have also obtained samples collected by the Greenland Fisheries and Environmental Research Institute. A number of the Greenland food samples were obtained from K.G.H. (The Royal Greenland Trade Company).

3.1.3.

The estimated mean diet in Grenland was the same as that in 1962, i.e., it agreed with the estimate given by the late Professor E. Hoff-Jørgensen, Ph.D.

3.1.4.

The environmental studies in Greenland were carried out together with corresponding investigations in Denmark (cf. Risø Report No. 540[3]) and in the Faroes (cf. Chapter 2 in this report).

3.1.5.

The present report does not repeat information concerning sample collection and analysis already given in ref. 2.

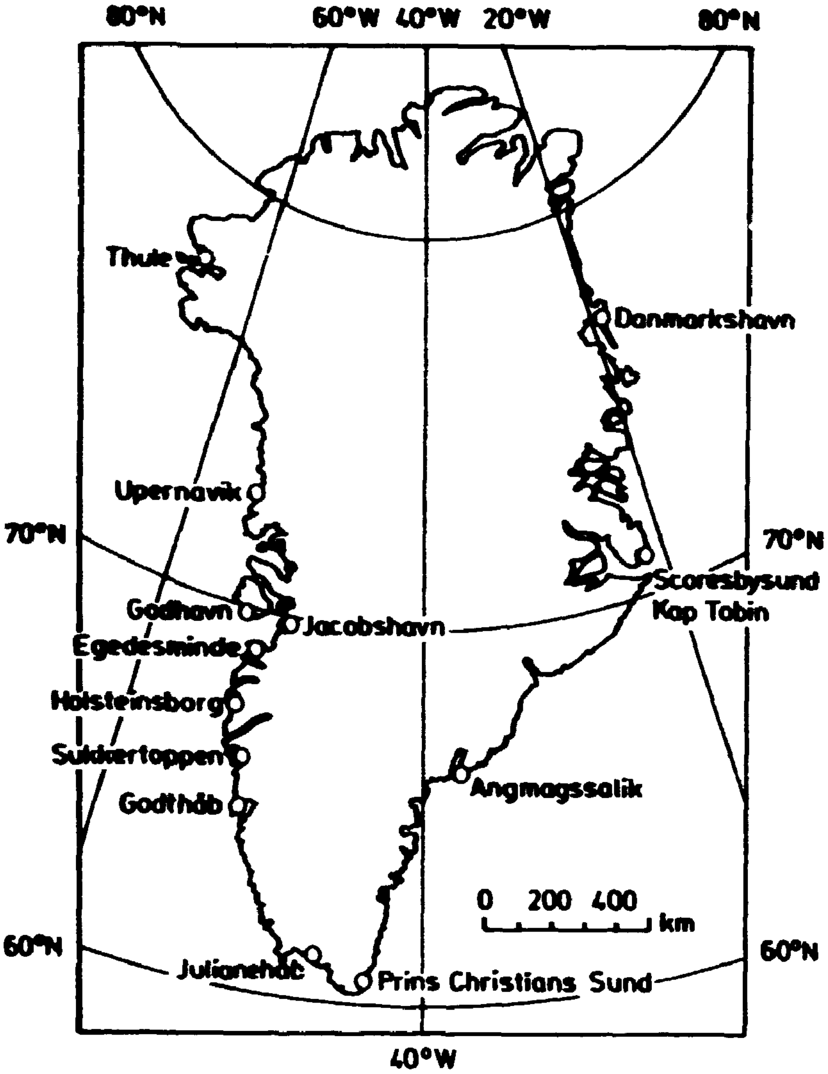


Fig. 3.1. Greenland

3.2. Results and discussion

3.2.1. Strontium-90 in Greenland precipitation

Table 3.2.1.1 shows the results of the measurements.

The ^{90}Sr fallout in 1985 at the Greenland stations were generally lower as compared with 1984. In Denmark[3)] and the Faroes (cf. 2.2.1) the fallout in 1985 was approximately 80% and 50% respectively of that in 1984.

Figure 3.2.1 shows the accumulated ^{90}Sr at the various stations in Greenland, since measurements began in 1962.

Table 3.2.1.1. Strontium-90 in precipitation in Greenland in 1985. (Sampling area: 0.02 m^2)

Location m precipitation	Unit	Jan-March	April-June	July-Sept	Oct-Dec	1985
Upernavik	Bq m^{-3}	8.1 A				
Σ	Bq m^{-2}	0.31 A				
Godthåb	Bq m^{-3}	(1.6)	(3.7)	2.5	1.9 B	(2.3)
Σ (0.73)	Bq m^{-2}	(0.41)	(0.64)	0.36	0.30 B	(1.7)
Prins Chr. Sund	Bq m^{-3}	1.82	0.91 A	0.98	(0.4)	(1.0)
Σ (1.61)	Bq m^{-2}	0.71	0.41 A	0.31	(0.18)	(1.6)
Scoresbysund	Bq m^{-3}	0.7 B	19.6 A	14.6 B	1.9 B	4.3
Σ 0.316	Bq m^{-2}	0.08 B	0.68 A	0.35 B	0.25 B	1.36
Danmarkshavn	Bq m^{-3}	7.5 B		26	2.4 B	11.6
Σ 0.087	Bq m^{-2}	0.32 B		0.64	0.05 B	1.01

Figures in brackets were calculated from VAR3[12]

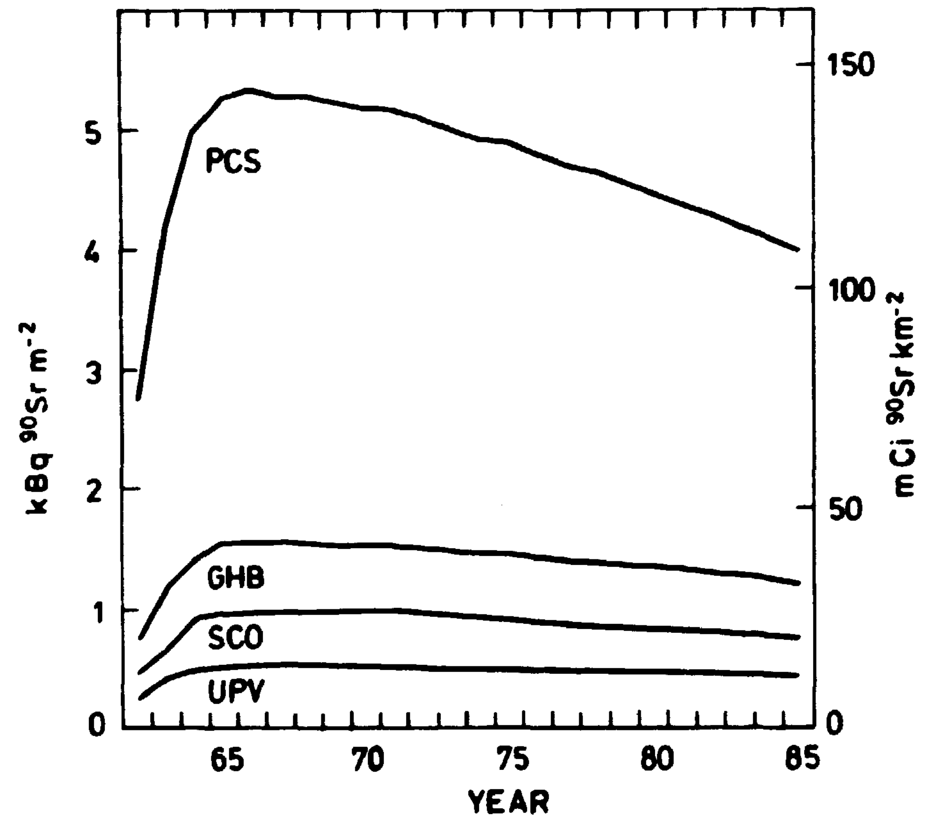


Fig. 3.2.1. Accumulated ^{90}Sr at Prins Chr. Sund, Godthåb, Scoresbysund (Kap Tobin) and Upernavik calculated from precipitation measurements since 1962. The accumulated fallout by 1962 was estimated from the Danish data (cf. Risø Report No. 509[3], Appendix D) and from the ratio between the ^{90}Sr fallout at the Greenland stations and the fallout in Denmark in the period 1962-1985.

Table 3.2.1.2. Fallout rates and accumulated fallout (Bq m^{-2}) in Greenland 1950-1985

	Scoresbysund (Kap Tobin)		Pr.Chr.Sund		Godthåb		Upernavik	
	di	$Ai_{(29)}$	di	$Ai_{(29)}$	di	$Ai_{(29)}$	di	$Ai_{(29)}$
1950	0.37	0.36	2.04	1.99	0.57	0.56	0.20	0.20
1951	1.76	2.06	9.79	11.50	2.77	3.25	0.97	1.14
1952	3.44	5.38	19.19	29.97	5.42	8.46	1.90	2.97
1953	8.70	13.74	48.47	76.59	13.69	21.63	4.81	7.60
1954	33.06	45.69	184.28	254.71	52.05	71.94	18.29	25.28
1955	43.49	87.08	242.45	485.41	68.48	137.10	24.06	48.17
1956	53.93	137.67	300.61	767.46	84.91	216.76	29.83	76.16
1957	53.93	187.08	300.61	1042.85	84.91	294.54	29.83	103.49
1958	74.81	255.70	417.04	1425.40	117.79	402.59	41.39	141.45
1959	106.11	353.27	591.53	1969.29	167.07	556.21	58.70	195.43
1960	19.82	364.28	110.51	2030.68	31.21	573.55	10.97	201.52
1961	25.75	380.83	143.57	2122.90	40.55	599.60	14.25	210.67
1962	129.17	497.95	720.07	2775.83	203.38	784.01	71.46	275.46
1963	290.45	769.78	1545.12	4218.89	475.45	1229.72	160.58	425.75
1964	180.93	928.26	929.07	5026.38	258.63	1453.19	100.27	513.59
1965	68.82	973.53	383.32	5281.93	166.50	1581.44	38.11	538.67
1966	37.37	987.02	207.94	5360.21	43.29	1586.36	20.72	546.18
1967	18.13	981.41	73.63	5305.51	32.56	1580.68	12.21	545.20
1968	24.42	982.08	136.16	5313.15	37.00	1579.48	13.32	545.33
1969	18.13	976.59	72.89	5258.83	22.20	1563.85	6.73	539.03
1970	33.30	986.03	59.20	5192.43	34.41	1560.51	12.58	538.58
1971	15.17	977.56	122.84	5189.73	32.56	1555.44	8.14	533.81
1972	12.58	966.75	55.50	5121.35	15.17	1533.52	4.07	525.17
1973	3.40	947.24	17.91	5017.88	6.92	1504.06	2.78	515.48
1974	12.21	936.79	45.88	4944.16	18.83	1486.92	13.14	516.13
1975	4.48	919.04	86.21	4911.57	19.57	1470.91	8.44	512.18
1976	3.00	900.26	11.17	4806.47	4.85	1440.91	2.44	502.46
1977	5.18	884.06	34.78	4726.91	14.06	1420.60	7.03	497.46
1978	10.36	873.29	54.39	4668.38	14.43	1401.14	7.77	493.30
1979	2.81	855.41	10.36	4568.24	9.99	1377.80	3.70	485.26
1980	2.57	837.72	5.74	4465.95	3.87	1349.04	3.02	476.75
1981	4.50	822.33	27.79	4387.60	10.57	1327.50	4.53	469.91
1982	1.97	804.83	5.19	4289.05	2.15	1298.24	1.27	460.05
1983	1.18	786.97	(10.1)	4197.63	2.98	1270.49	1.53	450.68
1984	0.87	769.23	(1.65)	4100.10	1.62	1242.06	1.79	441.78
1985	1.36	752.39	(1.6)	4004.82	(1.7)	1214.38	(~0.3)	431.64

3.2.2. Radionuclides in Greenland sea water

Table 3.2.2 shows the samplings carried out from land by local people in 1985. Further sea water data from Greenland are shown in Chapter 4 of this report.

Table 3.2.2. Radionuclides in surface sea water collected in Greenland in July-August 1985

Location	Bq ^{137}Cs m^{-3}	Bq ^{90}Sr m^{-3}	Salinity in o/oo
Danmarkshavn	2.94	3.52	18.9
Upernavik	3.14	2.30	32.0

3.2.3. Strontium-90 and Cesium-137 in Greenland terrestrial animals

Reindeer samples were obtained from Greenland in 1985. The mean level in reindeer meat was 216 Bq ^{137}Cs kg^{-1}. The sample of reindeer from K.G.H. contained 0.10 Bq ^{90}Sr kg^{-1} meat and in the bone we found 1380 Bq ^{90}Sr (kg Ca)$^{-1}$.

Table 3.2.3.1. Cesium-137 in reindeer meat collected in Greenland in 1985

Location		Month	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Godthåb	I	Summer	320	75000
- " -	II	- " -	300	75000
K.G.H.	I		27	7200
Mean			216	52000

Table 3.2.3.2. Cesium-137 and Strontium-90 in meat samples and bone (results in brackets) of lamb from Greenland obtained through K.G.H.

	Sample I	Sample II
Bq ^{137}Cs kg^{-1}	64	54
Bq ^{137}Cs $(kg\ K)^{-1}$	18000	15400
Bq ^{90}Sr kg^{-1}	0.174	0.106
Bq ^{90}Sr $(kg\ Ca)^{-1}$	4800 (3500)	2400 (2800)

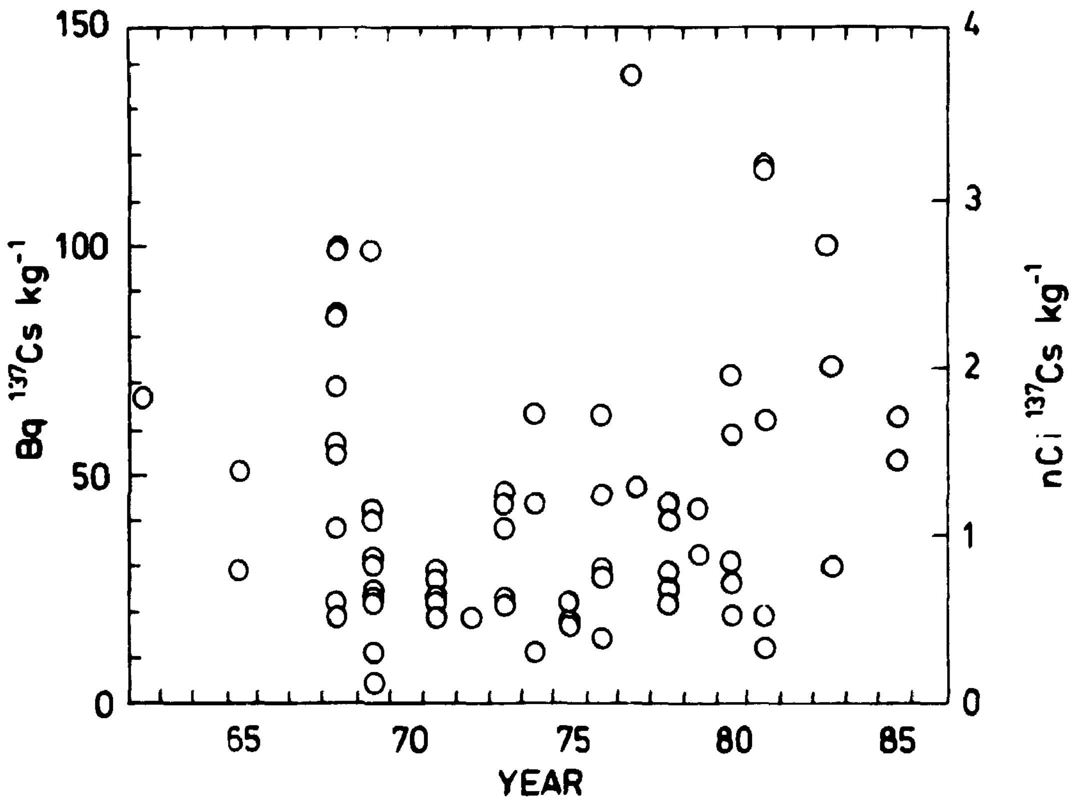


Fig. 3.2.3. Cesium-137 in Greenlandic mutton, 1962-1985.

3.2.4. Strontium-90 and Cesium-137 in Greenland sea animals

The results are shown in Tables 3.2.4.1 and 3.2.4.2. The mean concentrations in fish were: 0.0046 Bq ^{90}Sr kg^{-1} and 0.39 Bq ^{137}Cs kg^{-1}.

Table 3.2.4.1. Cesium-137 in sea animals collected in Greenland in 1985

Species	Location	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Seal	Godthåb	0.23	120
"	K.G.H.	0.27	101
Whale I	Godthåb	0.72	240
" II	- " -	0.87	250
Scallop	K.G.H.	0.13 B	32 B
Shrimps	K.G.H.	0.07 B	71 B
Salmon	K.G.H.	0.30	81
Cod	Godthåb	0.59	144
Catfish	K.G.H.	0.51	132
Angmagssats	Godthåb	0.17	44

Table 3.2.4.2. Strontium-90 in sea animals collected in Greenland in 1985

Species	Location	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$
Seal	Godthåb	0.001 B	23 B (0.7 B)
"	K.G.H.	0.001 B	23 B (1.9 B)
Whale	Godthåb	0.0023B	66 B
Scallop	K.G.H.	0.001 B	11 B
Shrimps	K.G.H.	0.018	26
Salmon	K.G.H.	0.0064	46 (44)
Cod	Godthåb	0.0029	43
Catfish	K.G.H.	0.0020	24
Angmagssats	Godthåb	0.0090	2.5

Bone levels are shown in brackets.

Whale meat contained 0.0023 Bq ^{90}Sr kg^{-1}, and 0.80 Bq ^{137}Cs kg^{-1}, and seal meat 0.001 Bq ^{90}Sr kg^{-1} and 0.25 Bq ^{137}Cs kg^{-1}. Figure 3.2.4 shows that the ^{137}Cs levels in seals and whales from Greenland decay with an effective half-life of 8-9 years. This is in agreement with the effective half-life of ^{90}Sr and ^{137}Cs observed in the surface waters of the North Atlantic ocean[21)].

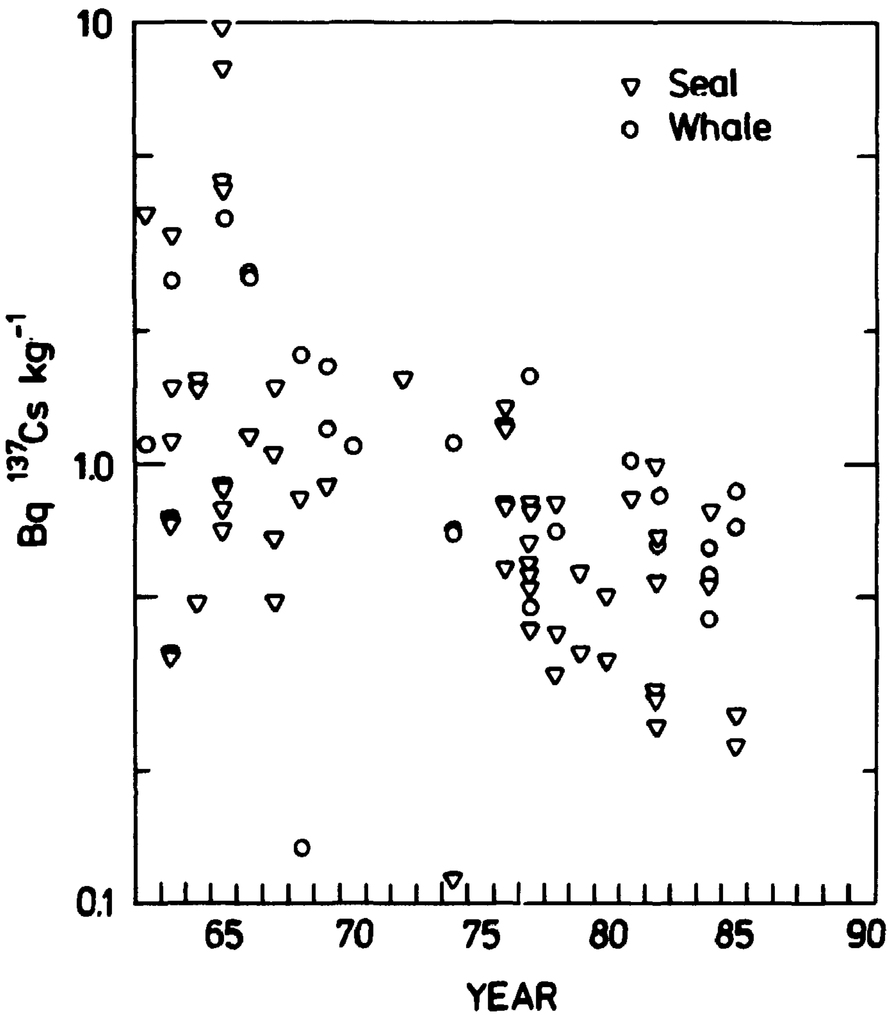


Fig. 3.2.4. Cesium-137 in seal- and whale meat from Greenlana 1962-1985.

3.2.5. Radionuclides in Greenland seaweed

No terrestrial samples of vegetation from Greenland were obtained in 1985. The Greenland Fisheries and Environmental Research Institute provided us with a number of seaweed samples collected from Scoresbysund on the east coast to Kamorilik on the west coast of Greenland. The mean contents in Fucus were 0.43 Bq ^{90}Sr kg^{-1}, 4.1 Bq ^{99}Tc kg^{-1}, and 1.1 Bq ^{137}Cs kg^{-1}. The concentrations at Mamorilik were lower than those at the other stations for all radionuclides measured.

Table 3.2.5.1. Strontium-90, ^{99}Tc and ^{137}Cs in seaweed samples collected along the Greenland coast in July-Sept 1985. (Unit: Bq kg^{-1} dry weight)

Location (N,W)	Species (date)	^{90}Sr	^{99}Tc	^{137}Cs	g K kg^{-1}	g Ca kg^{-1}
Vega Sund (72°39',22°29')	Fu.di. (Sept 14)	0.41 B	5.7	1.56 A	28.5	10.9
Angmagssalik (65°36',37°41')	Fu.ve. (Sept 22)	0.44	6.2	1.26	22.7	12.2
Kap Farvel (59°45',44°00')	Fu.ve. (Sept 29)	0.40	6.0	1.43	23.4	11.0
"Julianehåb" (60°21',45°16')	Fu. (July 15)	1.08	4.0	1.20	27.0	14.4
Tartoq (61°21',48°59')	Fu. (July 5)	0.57	6.1±0.3	1.05	32.6	13.4
Fiskenæsset (63°03',50°36')	Fu.	0.46	4.0	0.78	23.1	13.5
	As.no. (July 23)	0.92	6.8	0.42	22.4	11.5
Kaugarssup (65°10',52°18')	As.no. (Aug 7)	0.31	5.4	0.51	22.3	12 1
Mamorilik (71°03',51°00')	Fu.ve. I	0.24	2.2	0.45 A	26.3	9.7
	- " - II	0.26 A	2.6			9.0
	- " - III	0.27	2.4			9.5
	- " - IV (Sept 16)	0.15 A	1.9			12.7

Fu.di.: Fucus disticus; Fu.ve.: Fucus vesiculosus; Fu.: Fu.ve. or Fu.di.

As.no.: Ascophyllum nodosum.

Data on seaweed samples are furthermore shown in Chapter 4 of this report.

If we compare the ^{99}Tc values with those measured in earlier years[4], the levels on the east coast (the first three samples in Table 3.2.5.1) seem to have decreased a little since 1982. On the west coast, however, the southern stations are higher than those observed in 1982-1983. At Mamorilik the levels are similar to those measured at Thule (76°34'N, 68°48'W) in 1984. We may thus conclude that the ^{99}Tc off W-Greenland by 1984-1985 reached the coastal waters to its full extent.

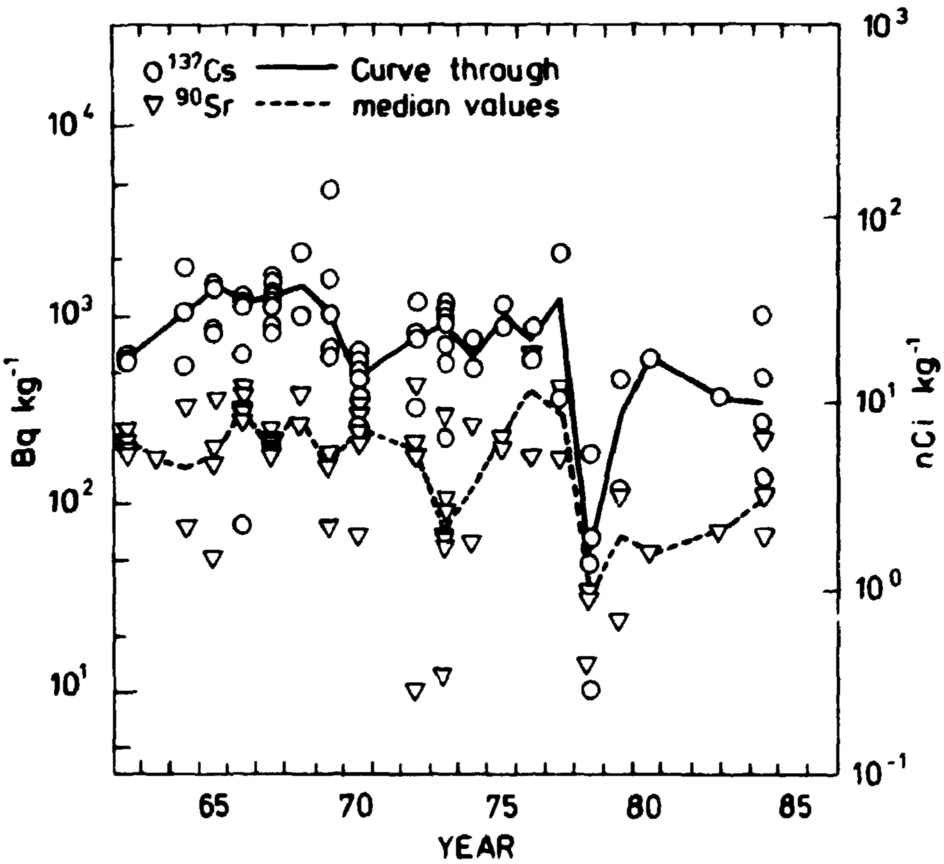


Fig. 3.2.5. Cesium-137 and Strontium-90 in lichen (fresh weight) collected along the Greenlandic coast, 1962-1984.

3.2.6. Strontium-90 and Tritium in Greenland drinking water

Quarterly samples of drinking water were collected from a number of locations in Greenland. Table 3.2.6.1 shows the results from 1985, and Fig. 3.2.6 the geometric annual means of all samples for the period 1962-1985.

As in previous years, we found it most expedient to choose the geometric mean of all figures, i.e. 16 Bq ^{90}Sr m^{-3} (0.43 pCi l^{-1}) as representative of the mean level of ^{90}Sr in Greenland drinking water in 1985, this level was a little higher than that observed in 1984 (Fig. 3.2.6). The levels in drinking water are still surprisingly high as compared to present rain concentrations (cf. Table 3.2.1.1). We have suggested that evaporation from the drinking water reservoirs was responsible for the higher ^{90}Sr levels. Tritium measurements show (Table 3.2.6.2) that the Greenland drinking water shows similar tritium levels as rain from Denmark[3)], hence evaporation seems to be a possible explanation. The high ^{90}Sr levels may, however, also be due to extraction of old deposited ^{90}Sr activity from the soil by the water collected for drinking. This would also be compatible with "normal" tritium concentrations.

Table 3.2.6.1. Strontium-90 in drinking water collected in Greenland in 1985. (Unit: Bq m^{-3})

Location	Jan-March	April-June	July-Sept	Oct-Dec
Danmarkshavn	29	23	6	18
Scoresbysund	12	9	7	10
Prins Chr.Sund	82	65	45	
Godthåb			9	
Upernavik	11	14	7	

Table 3.2.6.2. Tritium in drinking water collected in Greenland in 1985. (Unit: kBq m^{-3})

Location	Jan-March	July-Sept
Danmarkshavn	B.D.L.	
Scorebysund	B.D.L.	
Prins Chr.Sund	B.D.L.	
Godthåb	1.6±0.1	1.7±0.1
Upernavik	B.D.L.	

The error term is 1 S.E. of the mean of double determinations.

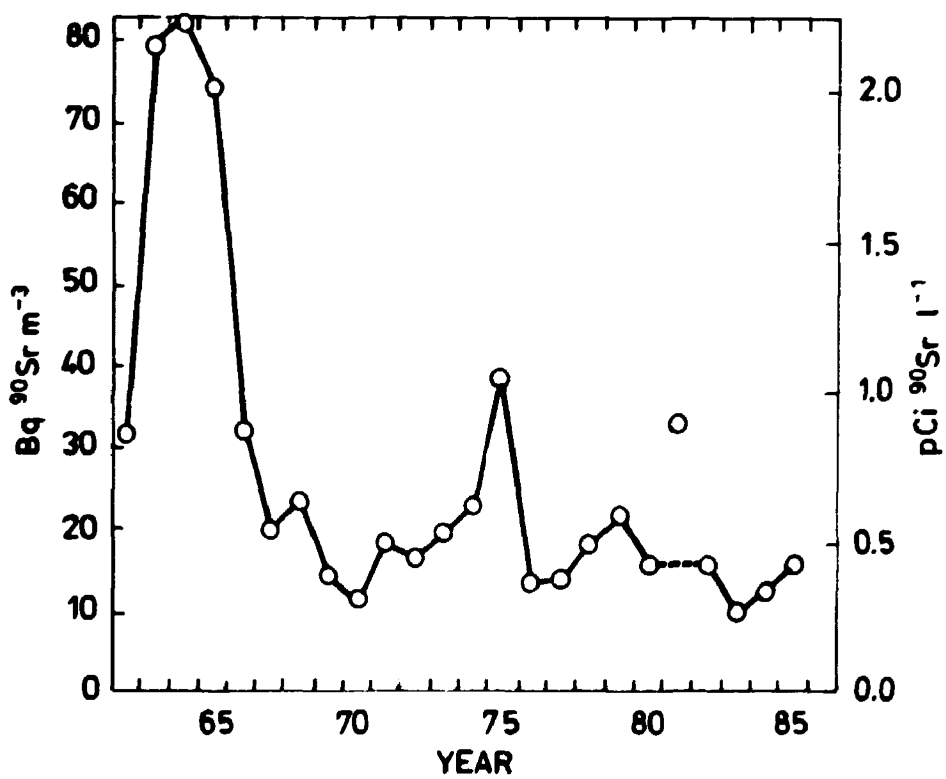


Fig. 3.2.6. Strontium-90 in Greenlandic drinking water (Geometric mean), 1962-1985.

3.3. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1985

3.3.1. The annual quantities

The estimate of the daily pro capite intake of the different foods in Greenland is still based on the figures given in 1962 by the late Professor E. Hoff-Jørgensen, Ph.D., in Risø Report No. 65[2].

3.3.2. Milk products

All milk consumed in Greenland was imported as milk powder from Denmark. The mean radioactivity content in milk prepared from Danish dried milk produced in 1985 was 0.072 Bq ^{90}Sr kg^{-1} and 0.076 Bq ^{137}Cs kg^{-1} [3].

Cheese was also imported from Denmark and contained 0.51 Bq ^{90}Sr kg^{-1} and 0.055 Bq ^{137}Cs kg^{-1}.

3.3.3. Grain products

All grain was imported from Denmark. It is assumed that only grain from the harvest of 1984 was consumed in Greenland during 1985. The daily pro capite consumption was: rye flour (100% extraction): 80 g, wheat flour (75% extraction): 110 g, rye flour (70% extraction): 20 g, biscuits (rye, 100% extraction): 27 g, and grits: 25 g. The content of ^{90}Sr in these five products was 0.30, 0.08, 0.06, 0.23, and 0.17 Bq kg^{-1}, respectively. Hence the mean content of ^{90}Sr in grain products was 0.17 Bq kg^{-1}. The content of ^{137}Cs in the five products was 0.16, 0.038, 0.08, 0.12 and 0.085 Bq kg^{-1}. Hence the mean content of ^{137}Cs in grain products was 0.09 Bg kg^{-1}.

The activity levels in rye flour (100% extraction), wheat flour (75% extraction), and grits were all taken from Tables 5.9.1 and 5.9.2 in Risø Report No. 509[3]. The ^{90}Sr level in rye flour (70% extraction) was calculated analogously with the level in wheat flour (75% extraction), i.e. as one-fifth of the whole-grain activity. The ^{137}Cs content in rye flour (70% extraction) was calculated as one half of the whole-grain level in rye in analogy with the ratio between ^{137}Cs in whole wheat grain and in wheat flour (75% extraction)[3]. The ^{90}Sr and ^{137}Cs contents in biscuits were calculated by dividing the levels of the rye flour (100% extraction) by 1.35, since 1 kg flour yields 1.35 kg bread[3].

3.3.4. Potatoes, other vegetables, and fruit

The Danish mean levels for 1985 were used[3] since the local production is insignificant compared with imports from Denmark.

The Danish mean levels were: in potatoes 0.056 Bq ^{90}Sr kg^{-1} and 0.078 Bq ^{137}Cs kg^{-1}, in other vegetables 0.24 Bq ^{90}Sr kg^{-1} and 0.052 Bq ^{137}Cs kg^{-1}, and in fruit 0.062 Bq ^{90}Sr kg^{-1} and 0.016 Bq ^{137}Cs kg^{-1}.

3.3.5. Meat

Nearly all meat consumed in Greenland is assumed to be of local origin. Approximately 10% comes from sheep, 5% from reindeer, 60% from seals, 5% from whales, and 20% from sea birds and eggs.

The activities in lamb were estimated from the 1983 data[2]. Reindeer, seal and whale were estimated from 3.2.3. The levels of sea birds and eggs were taken from the 1978 analyses[2]. Hence the mean levels in Greenland meat from 1985 were 0.08 Bq ^{90}Sr kg^{-1} and 12.3 Bq ^{137}Cs kg^{-1}.

(^{90}Sr: $0.1\times0.14 + 0.05\times0.10 + 0.6\times0.001 + 0.05\times0.0023 + 0.2\times0.007 = 0.02$ Bq kg^{-1})

(^{137}Cs: $0.1\times59 + 0.05\times216 + 0.6\times0.25 + 0.05\times0.80 + 0.2\times0.35 = 17.0$ Bq kg^{-1})

3.3.6. Fish

All fish consumed was of local origin, and the mean levels from 1985 (cod and salmon meat) were used, i.e. 0.0046 Bq ^{90}Sr kg^{-1} and 0.39 Bq ^{137}Cs kg^{-1}.

3.3.7. Coffee and tea

The Danish figures for 1985[3)] were used for coffee and tea, i.e. 1.00 Bq ^{90}Sr kg^{-1} and 1.53 Bq ^{137}Cs kg^{-1}.

3.3.8. Drinking water

The geometric mean calculated in 3.2.6 was used as the mean level of ^{90}Sr in drinking water, i.e. 16 Bq ^{90}Sr m^{-3}. The ^{137}Cs content was as previously[2)] estimated at 1/4 of the ^{90}Sr content, i.e. approximately 4 Bq ^{137}Cs m^{-3}.

Tables 3.3.1 and 3.3.2 show the diet estimates of ^{90}Sr and ^{137}Cs, respectively.

3.3.9. Discussion

The most important ^{90}Sr source in the Greenland diet is still grain products, which contribute 36% of the total ^{90}Sr content in the diet. Approximately 77% of the ^{90}Sr in the food consumed in Greenland in 1985 originated from imported (Danish) food.

Meat is still the most important ^{137}Cs source in the Greenland diet, contributing 91% of the total content in 1985. Approximately 97% of the ^{137}Cs in the Greenland diet in 1985 came from local products.

The ^{90}Sr contents in the total diet in 1985 was approximately 89% of the 1984 level.

The ^{137}Cs level was 137% of that found in 1984. As earlier discussed[2)] the great variations from year to year are primarily due to the variations in the ^{137}Cs levels in the meat samples obtained.

The ^{90}Sr content of the Greenland diet in 1985 was 81% of the estimated Danish mean content[3], and 69% of the Faroese level[1]. The ^{137}Cs level in the total diet in Greenland was 10.2 times that of the Danish diet and 87% of the Faroese diet level.

Table 3.3.1. Estimate of the mean content of ^{90}Sr in the human diet in Greenland in 1985

Type of food	Annual quantity in kg	Bq ^{90}Sr per kg	Total Bq ^{90}Sr	Percentage of total Bq ^{90}Sr in food
Milk and cream	78	0.072	5.62	12.6
Cheese	2.5	0.51	1.28	2.9
Grain products	95.6	0.17	16.25	36.3
Potatoes	32.8	0.056	1.84	4.1
Vegetables	5.5	0.24	1.32	3.0
Fruit	13.5	0.062	0.84	1.9
Meat and eggs	45.6	0.02	0.91	2.0
Fish	127.6	0.0046	0.59	1.3
Coffee and tea	7.3	1.00	7.30	16.3
Drinking water	548	0.016	8.77	19.6
Total			44.72	

The mean annual calcium intake is estimated to be 0.56 kg (approx. 0.2-0.25 kg creta praeparata). Hence the $^{90}Sr/Ca$ ratio in Greenland total diet in 1985 was 80 Bq ^{90}Sr (kg Ca)$^{-1}$ or 2.2 pCi ^{90}Sr (g Ca)$^{-1}$ and the daily intake was 0.12 Bq ^{90}Sr or 3.3 pCi ^{90}Sr.

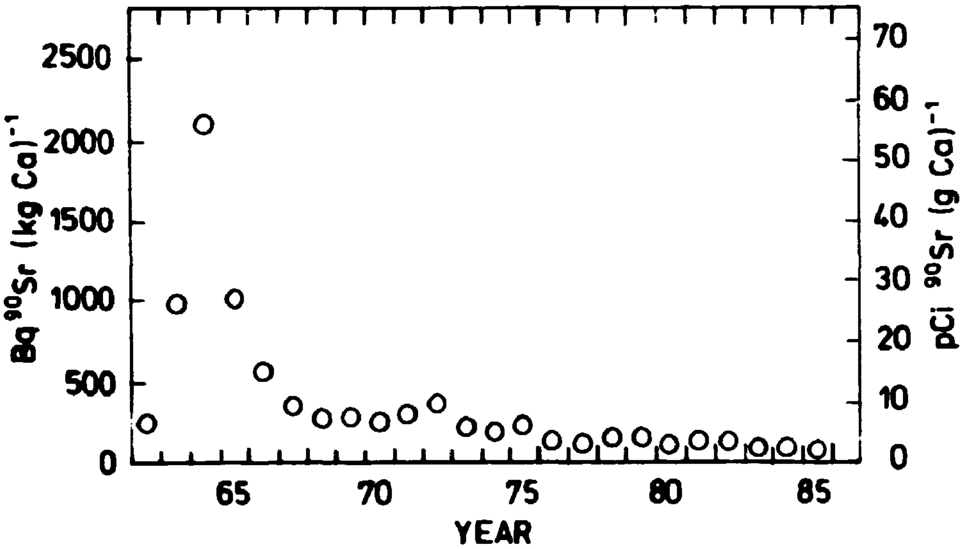


Fig. 3.3.1. Strontium-90 in Greenlandic diet, 1962-1985.

Table 3.3.2. Estimate of the mean content of ^{137}Cs in the human diet in Greenland in 1985

Type of food	Annual quantity in kg	Bq ^{137}Cs per kg	Total Bq ^{137}Cs	Percentage of total Bq ^{137}Cs in food
Milk and cream	78	0.076	5.93	0.7
Cheese	2.5	0.055	0.14	0.0
Grain products	95.6	0.09	8.60	1.0
Potatoes	32.8	0.078	2.56	0.3
Vegetables	5.5	0.052	0.29	0.0
Fruit	13.5	0.016	0.22	0.0
Meat and eggs	45.6	17.0	775.20	90.6
Fish	127.6	0.39	49.76	5.8
Coffee and tea	7.3	1.53	11.17	1.3
Drinking water	548	0.004	2.19	0.3
Total			856.06	

The mean annual potassium intake is estimated to be approx. 1.2 kg. Hence the ^{137}Cs/K ratio becomes 713 Bq ^{137}Cs (kg K)$^{-1}$ or 19.3 pCi ^{137}Cs (g K)$^{-1}$. The daily intake in 1985 from food was 2.35 Bq ^{137}Cs or 63 pCi ^{137}Cs.

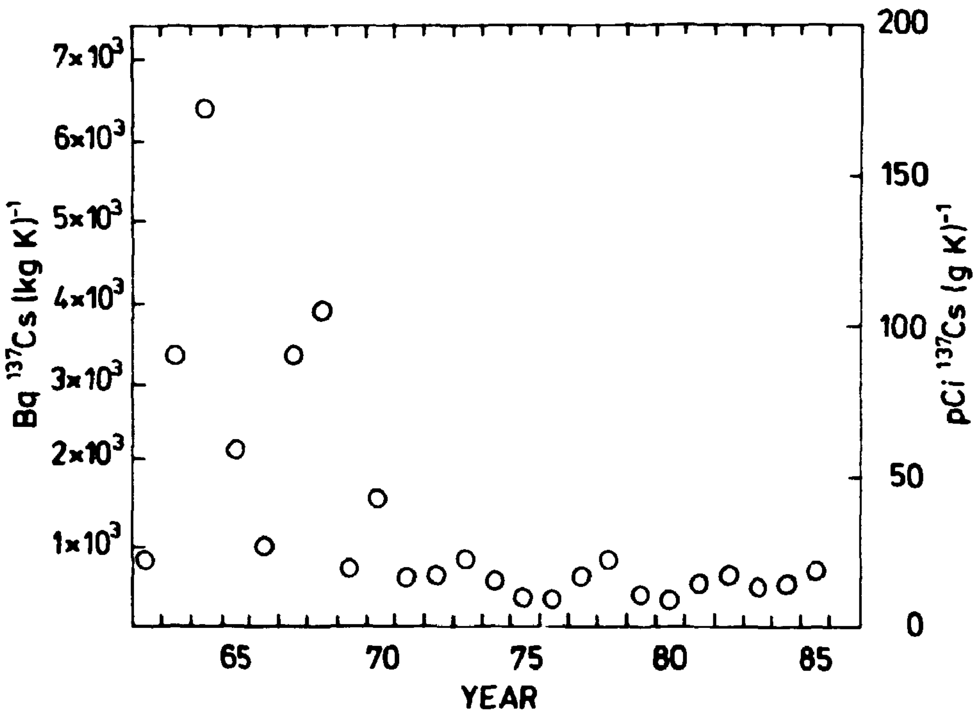


Fig. 3.3.2. Cesium-137 in Greenlandic diet, 1962-1985.

3.4. Conclusion

3.4.1.

The ^{90}Sr fallout rates in 1985 were the following: Prins Chr. Sund: approximately 1.6 Bq ^{90}Sr m^{-2}; Godthåb: 1.7 ; Scoresby Sund: 1.4; and Danmarkshavn: 1.0. The accumulated fallout levels by the end of 1985 were estimated at approximately 1210 Bq ^{90}Sr m^{-2} at Godthåb, 4000 at Prins Chr. Sund, and 430 at Upernavik.

3.4.2.

The food consumed in Greenland in 1985 contained on the average 80 Bq ^{90}Sr (kg Ca)$^{-1}$, and the daily mean intake of ^{137}Cs was estimated at 2.35 Bq. The most important ^{90}Sr contributor to the diet were grain products accounting for 36% of the total ^{90}Sr content of the diet. Cesium-137 originated mainly from meat (reindeer and lamb) and fish, contributing 97% of the total ^{137}Cs content of the diet.

3.4.3.

No ^{90}Sr analyses of human bone samples have hitherto been carried out on the population of Greenland. Considering the estimated ^{90}Sr levels in the diet, it seems probable[4], however, that the 1985 ^{90}Sr levels of humans in Greenland were on the average rather similar to those found in Denmark, i.e. the mean levels in human bone in Greenland were approximately 25 Bq ^{90}Sr $(kg\ Ca)^{-1}$ (vertebrae). From diet measurements the ^{137}Cs content in Greenlanders was estimated at 2000 Bq ^{137}Cs $(kg\ K)^{-1}$.

4. MARINE ENVIRONMENTAL RADIOACTIVITY IN THE NORTH ATLANTIC REGION

4.1. The F/S Polarstern cruise in July 1985 to the Fram Strait

Since the Polarstern cruise in 1984[4] the ^{137}Cs concentrations in the surface water between Norway and Svalbard (cf. Fig. 4.1.1.1) have remained unchanged. This was to be expected if the transit time from Sellafield to the Norwegian Sea is about five years[11]. The discharges from Sellafield in 1978 was: 4.1 PBq ^{137}Cs, in 1979: 2.6 PBq and in 1980: 3.0 PBq[13]. We observed a decrease in the Norwegian Sea from 1983 to 1984 corresponding to the marked decrease in the discharges from 1978 to 1979. From 1979 to 1980 the discharges increased a little and therefore there was no further decrease in the water concentrations from 1984 to 1985.

In the Fram Strait (Fig. 4.1.1.2) the ^{137}Cs concentrations were in general decreasing from east to west as also observed in 1983 and 1984. However, at two western stations around 7°W enhanced ^{137}Cs levels were observed. As the ^{90}Sr concentrations at these stations are similar to the neighbouring stations we assume that we see a strong Sellafield signal at the two western stations.

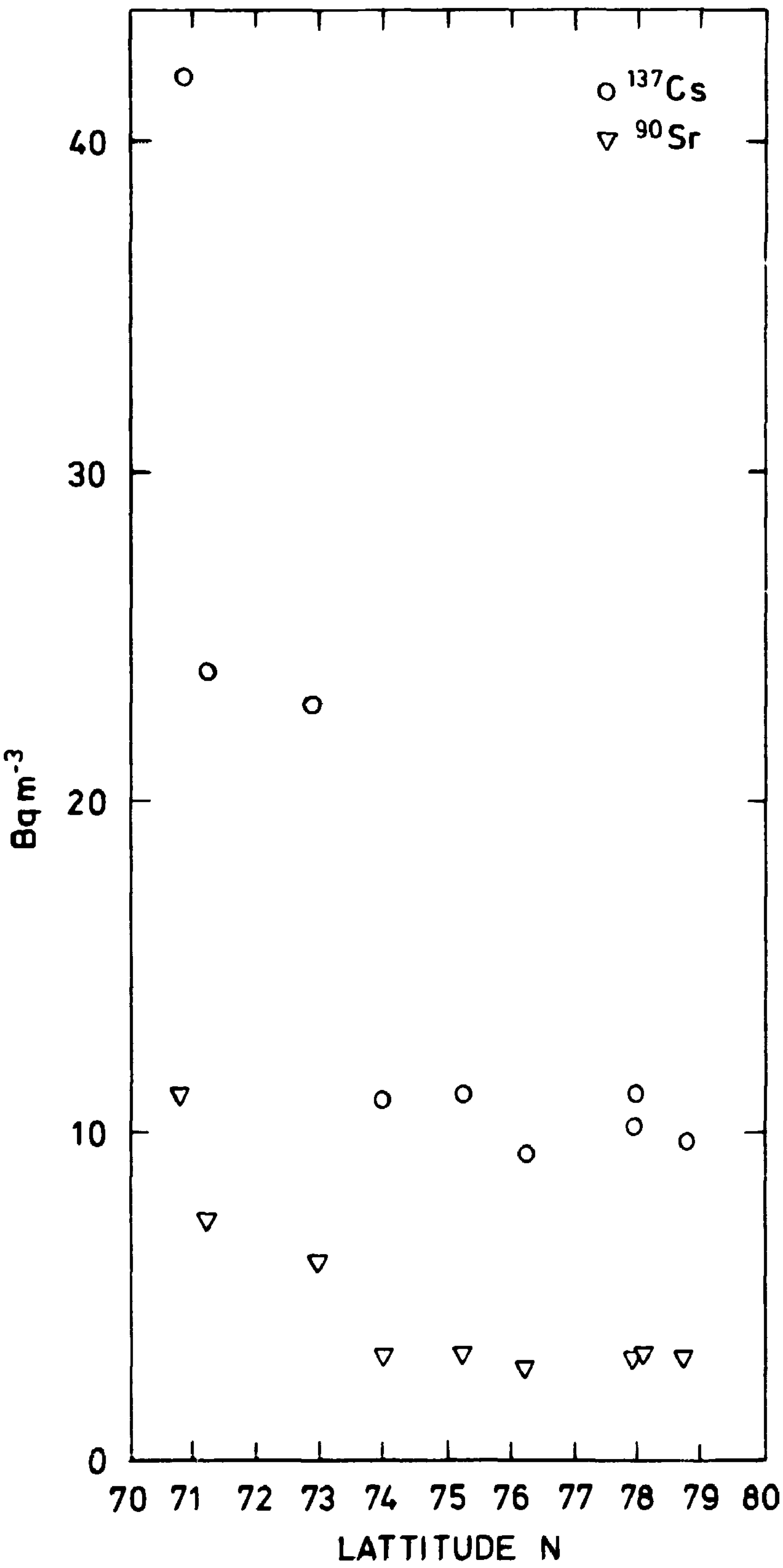


Fig. 4.1.1.1. Cesium-137 and Strontium-90 in surface water collected between N-Norway and Svalbard in July 1985. The abscissa shows the latitude of the samples.

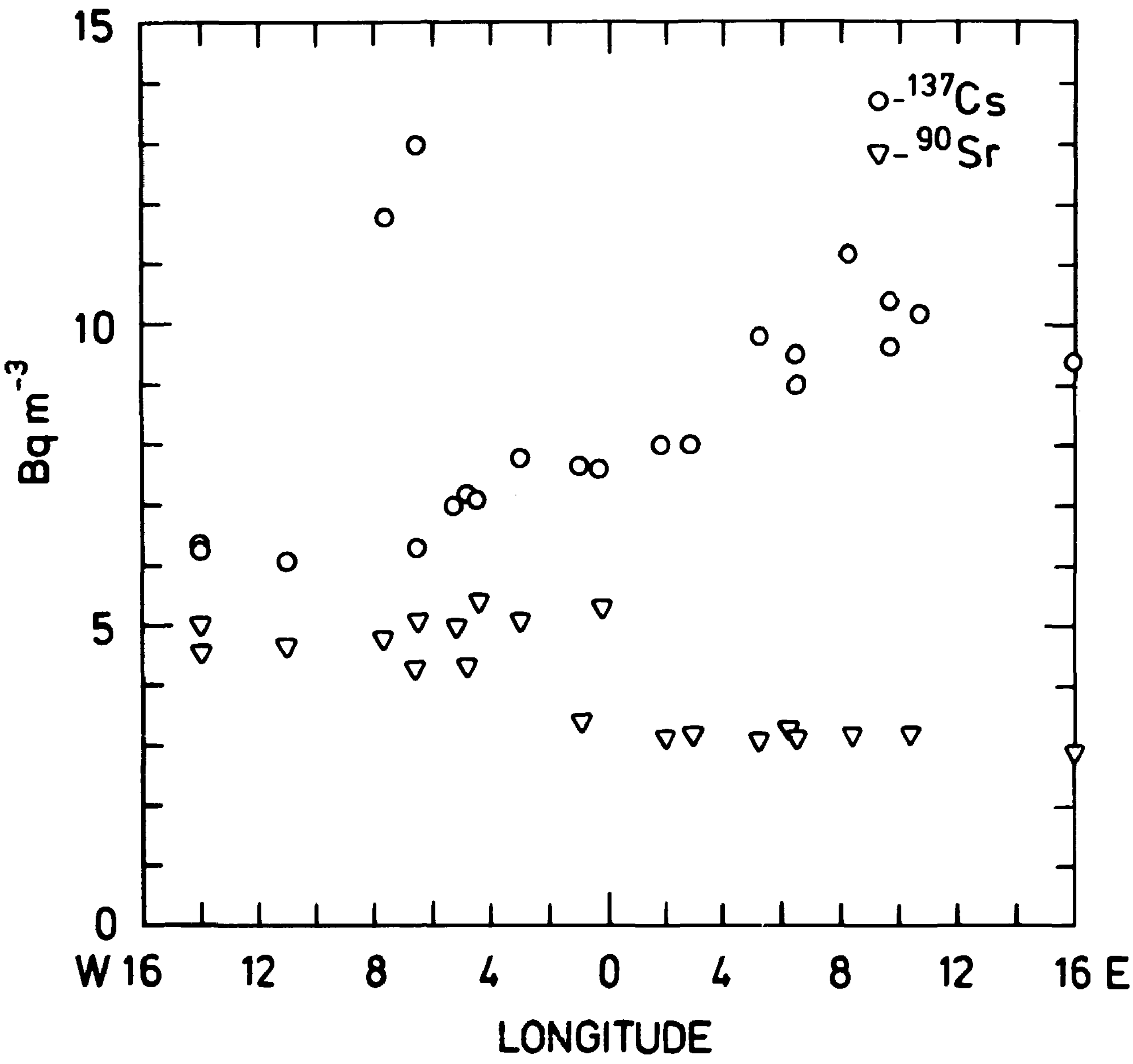


Fig. 4.1.1.2. Cesium-137 and Strontium-90 in surface water collected in the Fram Strait between Svalbard and East-Greenland in July 1985. (78-80°N). The abscissa shows the longitude of the samples.

We have combined a number of samples from the Fram Strait in order to measure the very low ^{134}Cs concentrations. From the western part of the Fram Strait we made three ^{134}Cs determinations (samples a), b), and c) in Table 4.1.1). The mean concentrations in these samples varied between 0.006 and 0.016 Bq ^{134}Cs m^{-3}. Assuming a transit time of 7 years[11] to the Fram Strait from Sellafield we may calculate a transfer factor from the ^{134}Cs discharge observed in 1978, which decay corrected to 1985 was: 0.038 PBq. Hence the transfer factor becomes 0.2-0.4 Bq ^{134}Cs m^{-3} per PBq ^{134}Cs discharged. From this and from the discharge in 1978 of ^{137}Cs (decay corrected to 1985) we would expect a concentration of $(0.2-0.4) \cdot 3.48 = (0.7-1.4)$ Bq m^{-3} ~ 1 Bq m^{-3} of Sellafield derived cesium-137 in the western part of the Fram Strait in 1985. The mean concentrations in the nine samples considered was 8.0±2.6 (± 1 S.D.) Bq ^{137}Cs m^{-3}. If the two "outliers" mentioned above are omitted in the mean, it becomes 6.7±0.6 (± 1 S.D., n=7). Using this mean, a realistic estimated of the global fallout background in the western Fram Strait becomes 5.7 Bq ^{137}Cs m^{-3}. In a similar way the ^{90}Sr fallout background is estimated as $\lfloor 4.9 \pm 0.35$ (± 1 S.D., n=9) - $0.3 \cdot 0.51 \rfloor = 4.7$ Bq ^{90}Sr m^{-3}. We have earlier[6] in 1983 estimated the fallout concentrations in polar water in the Fram Strait to 6.86 Bq ^{137}Cs m^{-3} and 5.72/1.225 = 4.67 Bq ^{90}Sr m^{-3} (cf. Introduction).

In the eastern part of the Fram Strait the transfer factor for Sellafield discharges was an order of magnitude higher than that observed in the western part.

A number of samples from the cruise have been analysed for ^{99}Tc. In nearly all cases the concentrations are similar to those observed for ^{134}Cs. This implies that the annual mean discharges of ^{99}Tc have been similar to the decay corrected annual mean discharge of ^{134}Cs, i.e. about 0.04 PBq. This figure is actually in the right order of magnitude for ^{99}Tc[9,13].

Table 4.1.1. Radionuclides in surface sea water collected from N-Norway via Svalbard to N.E.-Greenland in July 1985

Position N	Position E or W	Station No.	Date in July	Salinity o/oo	Temp. °C	^{90}Sr Bq m^{-3}	^{99}Tc Bq m^{-3}	^{134}Cs Bq m^{-3}	^{137}Cs Bq m^{-3}	$^{239,240}Pu$ mBq m^{-3}	$\frac{^{238}Pu}{^{239,240}Pu}$	^{241}Am mBq m^{-3}
54°29'	7°28'E	85601	3	30.9	-	37	-	-	20.1	-	-	-
58°20'	5°00'E	85602-05	4	29.7	-	25	1.3	1.34	53	7.7	0.19	-
60°04'	4°54'E	85606-07	5	29.9	-	21	1.4	2.03 A	49	-	-	-
63°15'	6°00'E	85608-09	6	-	-	-	0.66	-	-	9.1	-	0.34
63°30'	6°15'E	85610-11	6	33.3	-	12.8		1.09	55	-	-	-
65°30'	8°49'E	85612-13	6	33.6	-	10.4	0.51	-	39	-	-	-
68°23'	13°10'E	85614-15	7	-	10.5	-	-	-	-	5.8	-	0.81 A
68°37'	13°35'E	85616-17	7	33.8	11.4	13.1	-	0.82	45	-	-	-
70°40'	18°50'E	85618-19	8	33.9	8.3	11.0	0.40	-	42	-	-	-
71°08'	21°00'E	85620-21	8	-	8.7	-	0.29	-	-	6.5	-	0.80
71°15'	21°30'E	85622-23	8	34.7	8.5	7.1	-	0.41	24	-	-	-
72°54'	20°13'E	85624-25	9	34.8	7.7	6.0	B.D.L.	-	23	-	-	-
73°45'	19°05'E	85626-27	9	-	5.1	-	0.34	-	-	12.3 A	0.045 B	-
74°00'	18°45'E	85628	9	35.0	5.1	3.1	-	-	11.0	-	-	-
75°13'	17°42'E	85629-32	10	34.4	3.3	3.3	0.12	0.135A	11.2	8.4	0.047	0.56
76°22'	16°00'E	85633-34	10	34.7	3.5	2.9	0.34	-	9.4	-	-	-
77°54'	10°35'E	85635-36	11	35.0	5.4	3.2	-	-	10.2	-	-	-
77°55'	8°18'E	85637-39	11	35.1	5.2	3.2	-	0.154	11.2	11.9	-	1.45
78°42'	5°22'E	85640-43*	12	34.4	4.7	3.1	B.D.L.	0.159	9.8	-	-	2.5
78°27'	1°55'E	85647-49	13	33.1	0.5	3.1		0.036[e]	8.0	9.8	-	1.27
79°02'	0°52'W	85650-51*	14	33.0	0.0	3.4	-	0.036[e]	7.7	-	-	-
78°53'	3°06'W	85655-56	14	32.0	-1.6	5.1		0.011[b]	7.8			
78°59'	5°16'W	85657-60	16	31.4	-0.6	5.0	0.037	0.011[b]	7.0			0.38
78°31'	4°53'W	85661*	17	31.6	-0.2	4.3			7.2			

Table 4.1.1. (continued)

Position N	E or W	Station No.	Date in July	Salinity o/oo	Temp. °C	^{90}Sr Bq m^{-3}	^{99}Tc Bq m^{-3}	^{134}Cs Bq m^{-3}	^{137}Cs Bq m^{-3}	^{239,240}Pu mBq m^{-3}	^{238}Pu / ^{239,240}Pu	^{241}Am mBq m^{-3}
78°46'	6°27'W	85665-66	18	31.2	-0.5	4.3		0.011[b]	13.0			
79°02'	7°44'W	85667-68	18	31.1	-1.8	4.8		0.011[b]	11.8			
79°20'	14°07'W	85669-70	19	31.7	-0.5	5.0		0.0056B[a]	6.4			
79°20'	11°00'W	85671-72	19	31.5	-	4.6		0.0056B[a]	6.1			
79°40'	8°00'W	85674	20	-	0.4	-	-	-	-	-	-	0.50
80°00'	14°00'W	85675-77	21	32.1	0.0	4.5	0.21	0.0056B[a]	6.3			
80°00'	11°00'W	85678	21	-	0.0	-	-	-	-	7.6	-	0.86
80°00'	6°25'W	85679-80	22	32.1	1.6	5.1		0.016A[c]	6.3			
80°00'	4°28'W	85681-82	22	31.5	2.2	5.4	-	0.016A[c]	7.1	-	-	-
80°00'	3°00'W	85683	23	-	0.0	-	-	-	-	-	-	0.40
80°00'	0°08'W	85684-85	23	32.2	0.0	5.3		0.036[e]	7.6			
80°00'	2°50'E	85686-87	24	33.3	3.0	3.2		0.078[d]	8.0			
80°00'	4°25'E	85688	24	-	3.3					7.9	0.037	0.95
80°00'	6°30'E	85689-90	25	34.2	3.8	3.2		0.078[d]	9.5			
79°50'	9°46'E	85691-92	25	34.7	6.6	-	-	0.16	10.4	-	-	-
78°40'	6°20'E	85693-94	27	34.8	6.9	3.3			9.0			
78°30'	9°30'E	85695-96	28	34.9	5.8			0.12	9.6			

a) Three samples representing 5.35 m^3 combined to ^{134}Cs analysis.

b) Four samples representing 7.05 m^3 combined to ^{134}Cs analysis.

c) Two samples representing 3.5 m^3 combined to ^{134}Cs analysis.

d) Two samples representing 3.55 m^3 combined to ^{134}Cs analysis.

e) Three samples representing 5.3 m^3 combined to ^{134}Cs analysis.

*) Cf. corresponding deep-water samples in Table 4.1.2.

Table 4.1.2 shows the data for three sets of deep-water samples collected in the Fram Strait. The three stations all showed a decrease in activity from surface to 200 m. From 200 to 400 m the concentrations did not change very much. But from 400 to 700 m there was again a significant decrease. All the deep-water samples showed $^{137}Cs/^{90}Sr$ ratios significantly larger than those expected in global fallout (~ 1.45) indicating a significant contribution from Sellafield.

Table 4.1.2. Radionuclides in deep-water samples collected in July 1985 in the Fram Strait

Position N	Position E or W	Depth in m	Station No.	Date in July	Salinity o/oo	Temp. °C	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	$^{137}Cs/^{90}Sr$
78°42'	5°22'E	200	85644	12	35.2	2.5	2.5	6.9	2.8
- " -	- " -	400	85645	12	35.1	1.8	2.9	7.0	2.4
- " -	- " -	700	85646	12	35.0	-0.4	1.71	3.5	2.0
79°02'	0°52'W	200	85652	14	35.2	2.1	2.5	7.0	2.8
- " -	- " -	400	85653	14	35.0	1.9	2.2	7.7	3.5
- " -	- " -	700	85654	14	35.1	0.2	-	4.7	-
78°31'	4°53'W	200	85662	17	34.8	0.8	2.0	5.0	2.5
- " -	- " -	400	85663	17	35.1	1.1	2.0	4.2	2.1
- " -	- " -	700	85664	17	35.1	0.3	0.87	2.1	2.4

4.2. An estimate of the transfer factors of ^{137}Cs and ^{90}Sr from Sellafield to the East Greenland Current Based upon sea water samples collected off East Greenland in November 1984[4)]

The samples were collected in the EGC between 66°N and 61°N along the Greenland east coast:

Table 4.2.1.

Position	Bq ^{90}Sr m^{-3}	Bq ^{137}Cs m^{-3}
65°53'N 30°52'W	3.92	6.7
63°04'N 30°11'W	3.51	6.7
62°10'N 41°25'W	2.53	5.9
60°57'N 42°47'W	3.10	6.0
Mean	3.27	6.33
S.D.	0.59	0.43
S.E.	0.30	0.22

Another set of samples were collected outside the EGC. These samples are assumed to represent Atlantic water contaminated by fallout only

Table 4.2.2.

Position	Bq ^{90}Sr m^{-3}	Bq ^{137}Cs m^{-3}
65°45'N 28°17'W	1.55	2.7
63°38'N 40°05'W	1.63	2.15
61°56'N 40°27'W	1.47	2.5
60°48'N 41°16'W	1.44	2.5
Mean	1.52	2.46
S.D.	0.09	0.23
S.E.	0.04	0.11

In 1983 five samples of arctic water were collected in the Fram Strait at 79^{o}-80^{o}N and between $1^{o}09'$W and $12^{o}05'$W. These samples contained 4.70 Bq ^{90}Sr m^{-3} (1 S.D.: 0.64, 1 S.E.: 0.28), and 7.04 Bq ^{137}Cs m^{-3} (1 S.D.: 0.15, 1 S.E.:0.07). Samples collected in Atlantic water in 1983 contained:

Table 4.2.3.

Location		Bq ^{90}Sr m^{-3} (1 S.D.;1 S.E.;n)	Bq ^{137}Cs m^{-3}(1 S.D.;1 S.E.;n)
Norwegian coast	60^{o}-73^{o}N	10.4 (4.2;2.1;4)	45 (8.9;3.3;7)
Barents Sea	73^{o}-77^{o}N	3.76 (0.12;0.05;5)	13.8 (2.2;1.0;5)
Fram Strait East	79^{o}-82^{o}N	3.27 (0.24;0.07;11)	11.3 (1.24;0.37;11)

The fallout background in these samples was assumed to be 2 Bq ^{90}Sr m^{-3} and 3 Bq ^{137}Cs m^{-3}, respectively. The contributions of ^{90}Sr and ^{137}Cs from Sellafield were calculated by subtraction of the fallout background from the respective figures.

Let us now assume that the water seen in the EGC in 1984 between 66^{o} and 61^{o}W north (Table 4.2.1) consisted of 100x % Arctic water with the same concentrations of ^{90}Sr and ^{137}Cs as found in the western part of the Fram Strait in 1983[6], i.e. 4.70 Bq ^{90}Sr m^{-3} and 7.04 Bq ^{137}Cs m^{-3}.

Furthermore, there was a contribution of 100y % Sellafield-contaminated water coming from the Norwegian coastal Current with the concentrations 10.4 - 2 = 8.4 Bq ^{90}Sr m^{-3}, and 45 - 3 = 42 Bq ^{137}Cs m^{-3} (cf. Table 4.2.3), and finally 100(1-x-y) % of Atlantic water of the composition shown in Table 4.2.2.

The equations become:

$$^{90}Sr: 4.70x + 8.4y + (1-x-y)\cdot 1.52 = 3.27 \qquad (1)$$

$$^{137}Cs: 7.04x + 42y + (1-x-y)\cdot 2.46 = 6.33 \qquad (2)$$

The equations give $x = 0.4517$; $y = 0.0456$, and $(1-x-y) = 0.5027$.

We may instead assume that the Atlantic water with Sellafield effluents has the same composition as that from the Barrents Sea between 73° and 77°N (cf. Table 4.2.3). In that case the equations become:

$$^{90}Sr: 4.70x + 1.76y + (1-x-y)\cdot 1.52 = 3.27 \quad (3)$$

$$^{137}Cs: 7.04x + 10.8y + (1-x-y)\cdot 2.46 = 6.33 \quad (4)$$

$$x = 0.5376; \quad y = 0.1689, \text{ and } (1-x-y) = 0.2935$$

Finally, we may assume that the Sellafield contribution to the EGC has the composition seen in the eastern part of the Fram Strait (cf. Table 4.2.3) and we get:

$$^{90}Sr: 4.70x + 1.27y + (1-x-y)\cdot 1.52 = 3.27 \quad (5)$$

$$^{137}Cs: 7.04x + 8.3y + (1-x-y)\cdot 2.46 = 6.33 \quad (6)$$

$$x = 0.5674; \quad y = 0.2177, \text{ and } (1-x-y) = 0.2149$$

The concentrations of Sellafield derived ^{137}Cs in the EGC at 66°-61°N estimated from the 3 above determinations become $0.0456\times 42 = 1.92$ Bq m^{-3}; $0.1639\times 10.8 = 1.82$ Bq m^{-3}, and $0.2177\times 8.3 = 1.81$ Bq m^{-3}. The mean is 1.85 (1 S.D.:0.06; 1 S.E. = 0.04) Bq ^{137}Cs m^{-3}: This is from an annual mean discharges of 3.278 PBq ^{137}Cs (rel. S.D. 23%)[12,13]. Hence the transfer factor from Sellafield to the EGC becomes 0.56 Bq m^{-3} per PBq a^{-1}.

(relative S.D. estimated to $\sqrt{3^2\% + 23^2\%} = 23\%$)

(relative S.E. (3 areas) 13%)

In case of ^{90}Sr the 3 determinations gave:

$0.0456\times 8.4 = 0.38$ Bq $m^{-3}\cdot 0.1639\times 1.76 = 0.30$ Bq m^{-3}, and $0.2177\times 1.27 = 0.28$ Bq m-3. The mean is 0.32 (1 S.D.: 0.05; 1 S.E.:

0.03) Bq ^{90}Sr m^{-3}. This is from an annual discharge of 0.343 PBq (rel. S.D. 27%)[12,13], and the transfer factor then becomes 0.93 Bq m^{-3} per PBq a^{-1}. If we correct for contributions of ^{90}Sr from sources other than Sellafield[6] the factor becomes

$$0.93 \times 0.83 = 0.77 \text{ Bq } {}^{90}Sr \text{ m}^{-3} \text{ per PBq } {}^{90}Sr \text{ a}^{-1}$$

(relative S.D.: $\sqrt{17^2\% + 27^2\%}$ = 32%)

(relative S.E. (3 areas): 18%)

These transfer factors may be compared with those found for ^{134}Cs in water collected at west Greenland in August 1984. The mean of the 6 determinations was 0.68 Bq m^{-3} per PBq a^{-1} (1 S.D.:0.28, 1 S.E.:0.11), which is in good agreement with the above estimates[9].

Tranfer factors based on ^{99}Tc measurements in Fucus samples collected along the east and west coast gave 1.5 and 0.4 Bq m^{-3} per PBq a^{-1}, respectively[9]. It may be noticed that the water transfer factors are nearly the same on the east and west coast, whereas the factors based upon Fucus samples apparantly are lower on the west than on the east coast. This may be because the EGC runs close to the coastline on the east side of Greenland, but moves away from the coast when it has passed Kap Farwel and moves northward along the west coast (cf. also 3.2.5).

We presume that the 1983 data rather than those from 1984 from the Arctic and NE-Atlantic Ocean give the most correct answer because the water collected off East Greenland in 1984 due to transit time most likely corresponds to the water collected in the Arctic and the NE Atlantic Ocean in 1983.

4.3. Radioecological studies along the English channel in 1983

In samples collected from the German Bight and along the west coast of Jutland we have in recent years[1] seen radionuclide ratios: $^{90}Sr/^{137}Cs$, $^{134}Cs/^{137}Cs$ and $^{99}Tc/^{137}Cs$ definitely higher than those expected in effluents from Sellafield in the U.K. and we have assumed that this was an indication of a contribution of activity from Cap de la Hague in France.

In a joint French, Swedish and Danish effort samples of sea water, sea weed and mussels were collected in the first half of 1985 from the Continental as well as from the British side of the English Channel.

The samples have been analysed for γ-emitters by Ge(Li) spectroscopy, for ^{90}Sr, ^{99}Tc, and transuranics by radiochemistry at Lund University and Risø National Laboratory.

The purpose of the study was to see how the discharges from the two European reprocessing plants Cap de la Hague and Sellafield, and from other sources influenced the radioactivity levels in the English Channel and the southeastern part of the North Sea.

Figure 4.3.1 shows the water mass transport from Cap de la Hague according to Kautsky[23]. In Table 4.3 the results of the measurements are presented. It appears that the concentrations in sea weed and sea plants decrease after power functions with the distance from la Hague as shown in Figs. 4.3.2-4.3.6. A detailed discussion of the results has been given elsewhere[24].

Table 4.3. Radionuclides in seaweed and surface sea water along the English Channel in 1985
(Unit: Bq kg^{-1} dry weight for seaweed and Bq m^{-3} for sea water)

Station number	Species	Date	Position N	Position E or W	Location	Km*	% dry matter	Salinity in o/oo	^{40}K**	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{137}Cs	^{238}Pu	$^{239,240}Pu$	^{241}Am
85501	Fu.ve.	9/4	53°52'	8°43'E	Cuxhaven (D)	940			26.1			70			2.3			
85502	Seawater	"	"	"	"	"		11.0			24	1.6						
85503	Fu.ve.	"	53°37'	7°10'E	Norddeich (D)	835	18.7		35.5	2.4	5.2	200		1.6 A	2.1	0.013	0.030	
85504	My.ed.	"	"	"	"	"	13.3		17.4	1.05	0.056		6.5 A		1.89			
85505	Fu.ve.	10/4	53°10'	5°24'E	Harlingen (NL)	720			32.3	8.1		280			1.4			
85506	Seawater	"	"	"	"	"		11.0				11.7						
85507	Fu.ve.	"	52°28'	4°36'E	IJmuiden (NL)	595	23.8		31.6	3.2	4.1	124	4.3 A	1.55	2.3		0.022	0.011
85508	Seawater	"	"	"	"	"		15.2			33	2.2						
85509	Fu.ve.	"	51°27'	3°36'E	Vlissingen (NL)	435			32.4			360			1.4			
85510	Fu.ve.	11/4	51°14'	2°55'E	Oestende (B)	390	19.6		35.6	5.4	4.7	200	3.8 B	2.0	1.97		0.035	0.023
85511	Seawater	"	"	"	"	"		30.7			40	4.4						
85512	Fu.ve.	"	50°58'	1°51'E	Calais (F)	305			29.0	6.9		250			1.8			
85594	Fu.ve.	24/6	50°46'	1°37'E	Wimereux (F)	280	14		40.8	17.6	4.3	780	13.9 A	4.7	3.9	0.046	0.096	
85513	Fu.ve.	11/4	50°52'	1°35'E	Cap Gris-Nez (F)	290	11.9		45.9	7.6	5.1	670	8.2 A	[illegible].4	2.9	0.043	0.088	0.029
85514	Seawater	"	"	"	"	"		31.0				3.6						
85515	Fu.ve.	"	50°04'	1°22'E	Le Treport (F)	240			29.2	9.4		350	11.3		2.0			
85516	Seawater	12/4	"	"	"	"		5.2			10.7	0.48						
85593	Fu.ve.	4/7	"	"	"	"	20		31.8	32	4.7	670	23	3.8	3.1	0.077	0.169	
85517	Fu ve.	12/4	49°52'	0°42'E	St.Valery-en-Caux (F)	[illegible]00	18.1		41.1	14.3	5.6	1350	12 B	3.0 A	3.0	0.083	0.20	0.026
85518	Fu.se.	"	"	"	"	"			33.3	10.8		620	21.7		1.0			
85519	Seawater	"	"	"	"	"		31.1				4.4						
85592	Fu.ve.	4/7	"	"	"	"	19		41.8	28	4.8	1370	17.3	3.2	4.0	0.076	0.150	
85520	Fu.ve.	12/4	49°46'	0°22'E	Fécamp (F)	170	19.6		38.7	12.2	5.5	906	16.9	2.8	2.6	0.093	0.199	0.050
85521	Fu.se.	"	"	"	"	"			32.7	13.4		540	22		1.9			
85522	Seawater	"	"	"	"	"		32.3				6.1						
85591	Fu.ve.	4/7	49°30'	0°06'E	Le Havre (F)	150	20		48.8	14.8	4.5	380		2.9 A	4.8			
85590	Fu.ve.	5/7	49°17'	0°18'W	Luc sur Mer (F)	125	17		40.3	17.1	6.1	730	13.6 A	4.8	3.9	0.050	0.054	
85523	Fu.ve.	12/4	49°21'	0°45'W	Port-en-Bessin (F)	105	18.4		34.6	13.7	6.5	450	23	3.3 A	2.8	0.107	0.184	0.088
85524	Seawater	"	"	"	"	"		32.9				6.4						
85525	Fu.ve.	"	49°34'	1°16'W	St.Vast-la-Hague (F)	75			33.7	14.7	6.9	790	10.7 B	3.4 A	2.6	0.080	0.27	
85526	As.no.	"	"	"	"	"	22.1		30.2	7.9	6.4	1180	13.2 A	5.0	2.8	0.092	0.136	0.073

Table 4.3. (continued)

Station number	Species	Date	Position N	E or W	Location	Km*	% dry matter	Salinity in o/oo	^{40}K**	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{137}Cs	^{238}Pu	$^{239,240}Pu$	^{241}Am
85527	Fu.sp.	12/4	49°34'	1°16'W	St.Vaast-la-Hague (F)	75			30.2	13.4	5.6	470	27 A	4.8	2.0	0.064	0.125	
85528	Pe.ca.	"	"	"	"	"	52.9		22.8	9.9	4.9	760	14.8 A	43	2.0	0.057	0.125	0.042
85529	Seawater	"	"	"	"	"						3.8						
85589	Fu.ve.	27/6	"	"	"	"	20	33.4	37.0	23	6.4	790	13 B	4.9	4.0	0.068	0.174	
85530	Fu.ve.	13/4	49°42'	1°16'W	Ptr.de Barfleur (F)	55			35.3	46	8.0	1500	30	4.2 A	3.6	0.125	0.35	
85531	Fu.se.	"	"	"	"	"	17.1		37.1	52	7.7	1100	53	6.2	4.1			0.24
85532	As.no.	"	"	"	"	"			30.1	16.5	6.9	2100	48	6.5	2.7	0.22	0.43	
85533	Pe.ca.	"	"	"	"	"	24.1		23.9	18.3	1.14	980		12.9	2.3	0.096	0.175	
85534	Pa.vu.	"	"	"	"	"	18.0		13.8	14.5	8.3		119	10.4	5.9			
85535	Seawater	"	"	"	"	"						12.1						
85536	Fu.ve.	"	49°42'	1°28'W	Cap Lévy (F)	40		34.1	33.7	88		1640	53		4.1			
85588	Fu.ve.	27/6	49°41'	1°28'W	Fermanvill (F)	"	18		42.2	56		1450	36 A	4.5 B	3.5	0.194	0.172	
85537	Fu.se.	13/4	49°43'	1°52'W	Le Hable (F)	11	19.8		42.7	200	10.0	2400	153	6.7	4.8	0.44	0.79	0.45
85538	Fu.sp.	"	"	"	"	"			32.5	123		2200	65		3.4			
85539	Seawater	"	"	"	"	"		34.9			89	17.1						
85540	Fu.sp.	"	49°43'	1°56'W	Goury,Cap de la Hauge(F)	6	23.4		36.8	200.3	20	2300	184	11.8	12.0	0.42	0.67	
85587	Fu.ve.	24/6	"	"	"	"	18		33.4	260	6.3	4700	127		5.2	0.51	0.55	
85585	Fu.se.	11/4	49°40'	1°56'W	Herquemoulin (F)	-6	17	31.1	49.6	410	15	4300	250	8.8 A	7.2	0.55	0.94	2.25
85586	Fu.se.	2/7	"	"	"	"	21		47.2	270	3.8	3600	184	4.4 B	5.2	0.42	0.48	
85584	Fu.ve.	1/7	49°22'	1°48'W	Carteret (F)	-38	30		40.1	48	3.5	1700	24 A	3.8 B	4.1			
85583	Fu.ve.	"	48°50'	1°35'W	Granville (F)	-101	20		36.5	26	3.7	1210	17 A	2.1 A	2.3			
85582	Fu.ve.	4/7	48°41'	1°51'W	Cancale (F)	-114	24		33.5	18.6	3.5	750	15.3	2.0 A	3.2			
85545	Fu.ve.	14/4	48°38'	2°02'W	Saint Malo (F)	-120			31.7	9.2		800	6.7		0.7			
85546	Fu.se.	"	"	"	"	"	27.2		38.9	15.1	2.6	460	9.5 A	1.8 A	1.63	0.098	0.24	0.064
85547	As.no.	"	"	"	"	"			38.2	7.3		1260			1.8			
85548	Fu.sp.	"	"	"	"	"	35.8	32.9	32.0	12.8	3.5	500	5.6 B	1.7 A	1.35		0.120	B.D.L.
85549	Pe.ca.	"	"	"	"	"			22.9	6.1		650			0.9			
85581	Fu.ve.	4/7	48°31'	2°45'W	St.Brieuc (F)	-134	24		30.8	36	3.0	1020	23	1.8 A	1.66	0.087	0.146	0.027
85544	Fu.ve.	14/4	48°50'	3°28'W	Perros Guirec (F)	-145	19.8		42.7	1.36	0.39	46			0.74 A		0.059	
85541	Fu.ve.	13/4	48°43'	3°58'W	Roscoff (F)	-185			42.2		0.27	12.6			0.89		0.102	
85542	Fu.se.	"	"	"	"	"	21.8		49.9		0.44	3.3			1.10 A		0.089	0.011

Table 4.3. (continued)

Station number	Species	Date	Position N	E or W	Location	Km*	% dry matter	Salinity in o/oo	^{40}K**	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{137}Cs	^{238}Pu	$^{239,240}Pu$	^{241}Am
85543	As.no.	13/4	48°43'	3°58'W	Roscoff (F)	-185			32.1		0.29	14.9			0.46A	0.041	0.138	
85580	Fu.ve.	26/6	"	"	"	"	20		45.8	7.6	0.25	116			0.7 B		0.094	0.98
85550	Fu.ve.	20/4	50°04'	5°42'W	Sennen Cove (GB)	27	20.6		42.9	1.84	0.27	54			0.68		0.053	0.011
85551	Seawater	"	"	"	"	"		35.1				2.0						
85552	Fu.ve.	"	50°01'	5°05'W	Coverack (GB)	230			36.9	2.3		81						
85553	Fu.ve.	"	50°14'	3°51'W	Hope Cove (GB)	150	31.0		35.1	7.7	0.41	145	3.6 B		0.74	0.017	0.105	0.008
85554	Fu.se.	"	"	"	"	"			38.3	6.8		115			1.2			
85555	Seawater	"	"	"	"	"		34.9				0.5						
85556	Fu.sp.	21/4	50°34'	2°26'W	Bill of Portland (GB)	105	18.3		35.7	46	0.46	134			1.1 A	0.0174	0.073	
85557	Seawater	"	"	"	"	"		35.0				2.1						
85558	Fu.sp.	"	50°37'	1°57'W	Swanage (GB)	"			32.8	224		119						
85559	Fu.sp.	"	50°43'	0°43'W	Selsey (GB)	145	20.5		30.5	42	0.98	219			1.3 A	0.0116	0.031	0.013
85560	Seawater	"	"	"	"	"		33.8				0.83						
85561	Fu.sp.	"	50°44'	0°12'E	Birling Gap (GB)	195			51.8	55	0.77	310						
85562	Fu.ve.	"	"	"	"	"	18.7		41.8	77		700			1.6 A	0.025	0.079	0.017
85563	Fu.se.	"	"	"	"	"			55.4	228		320						
85564	Fu.sp.	22/4	51°06'	1°13'E	Dover (GB)	275	16.5		33.6	24	0.65	156			1.65	0.0105	0.041	0.09
85565	Seawater	"	"	"	"	"		34.9			21	2.3						
85566	Fu.ve.	"	51°21'	1°27'E	Broadstairs (GB)	305			44.8	13.8		300±20			1.8			
85567	Fu.se.	"	"	"	"	"	20.3		34.7	15.0	0.91	156			2.6	0.0165	0.014	0.020
85568	Fu.sp.	23/4	51°56'	1°17'E	Harwich (GB)	340			29.8	4.4		110			7.4			
85569	Fu.se.	"	"	"	"	"	19.8		35.6	7.6	1.53	104			11.3		0.038	0.044
85570	Seawater	"	"	"	"	"		34.2				0.76						
85571	Fu.ve.	"	55°29'	8°25'E	Esbjerg N (DK)	1160	23.7		24.9	1.15	4.3	200		1.4 A	2.4			
85572	Seawater	"	"	"	"	"		26.6				2.5						
1193	Fu.ve.	19/4	55°28'	8°24'E	Esbjerg S (DK)	"	21.6		29.3	1.38	4.2	320		2.1 A	3.1			0.030
1194	Seawater	"	"	"	"	"		22.9				2.0						
85573	Fu.ve.	25/4	55°05'	8°34'E	Rømø (DK)	1100	19.3		30.6	1.0 A	3.3	190			3.4			
85574	Seawater	"	"	"	"	"		27.1				1.27						
1189	Fu.ve.	18/4	55°09'	8°34'E	"	"	19.6		31.3	0.78A	3.6	102			3.1		0.027	0.040

Table 4.3. (continued)

Station number	Species	Date	Position N	E or W	Location	Km*	% dry matter	Salinity in o/oo	^{40}K**	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{137}Cs	^{238}Pu	$^{239,240}Pu$	^{241}Am
1190	Fu.ve.	18/4	$55^{\circ}05'$	$8^{\circ}34'E$	Rømø (DK)	1100	21,2		28.6	0.71A	3.9	240		1,1 A	3,2			0,0167
1191	My.ed.	"	"	"	"	"	14 6		8.42	0.78	0.019B		4.9 A		1,34			
1192	Seawater	"	"	"	"	"		25.1			31	2.9						
1183	Fu.ve.	17/4	$54^{\circ}08'$	$8^{\circ}52'E$	Büsumhafen (D)	990	17.9		26.0		3,4	81			2,2			0,043
1184	Seawater	"	"	"	"	"		24.5				2.6						
1185	Fu.ve.	"	$54^{\circ}31'$	$8^{\circ}50'E$	Norderhafen (D)	1030	20.7		29.2	0.84	3.5	230		1,5 A	2,3		0,027	0,0063
1186	Seawater	"	"	"	"	"		28.1				3.5						
1187	Fu.ve.	18/4	$54^{\circ}44'$	$8^{\circ}43'E$	Dagebüllhafen (D)	1060	23.8		26.4	0,76A	3,5	118		1,7 A	2,8		0,091	0,049
1188	Seawater	"	"	"	"	"		28.5				3.5						
1184					Büsumhafen/							119						
1186	Seawater	17/4	~$54^{\circ}31'$	$8^{\circ}50'E$	Norderhafen/ (D)	~ 990		~ 27										
					Dagebüllhafen										16,7			

* Shortest sea distance from Cap de la Hague in Km

**Unit: g K kg^{-1} dry weight

Fu.ve.: Fucus vesiculosus, Fu.se.: Fucus serratus, Fu.sp.: Fucus epiralis, As.no.: Ascophyllum nodosum, Pe.ca.: Pelvetia canaliculata, Pa.vu.: Patella vulgata, My.ed.: Mytilus edulis.

85507: 0.12 B In these four samples it was possible to determine ^{134}Cs, and the $^{134}Cs/^{137}Cs$ ratios
85510: 0.11 B were calculated. In the samples collected close to Cap de la Hague the background
85534: 0.34 was too high for a reliable ^{134}Cs.
85540: 0.14

A: counting error 20-33%
B: counting error > 33%

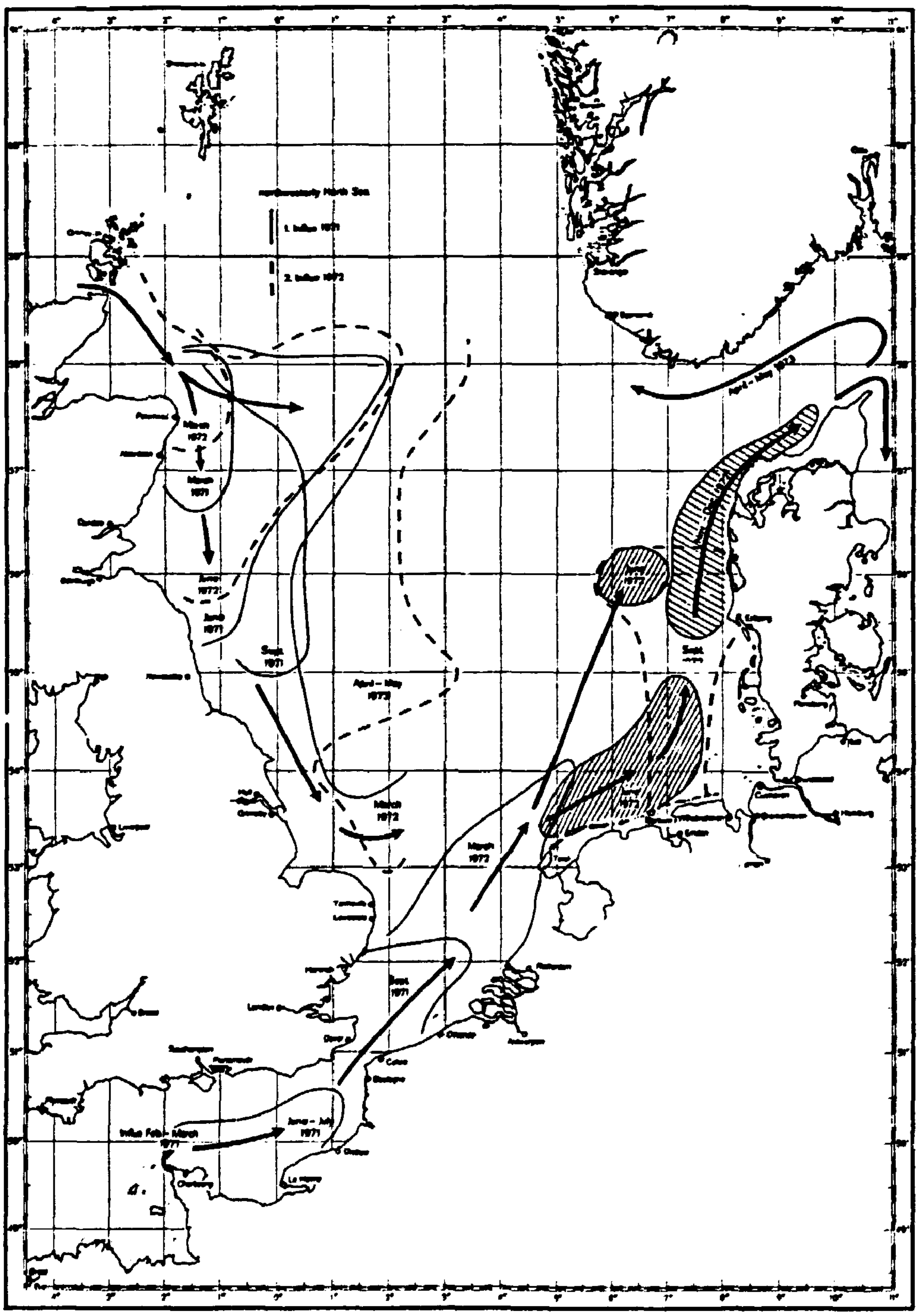


Fig. 4.3.1. The water mass transport from La Hague according to Kautsky[23].

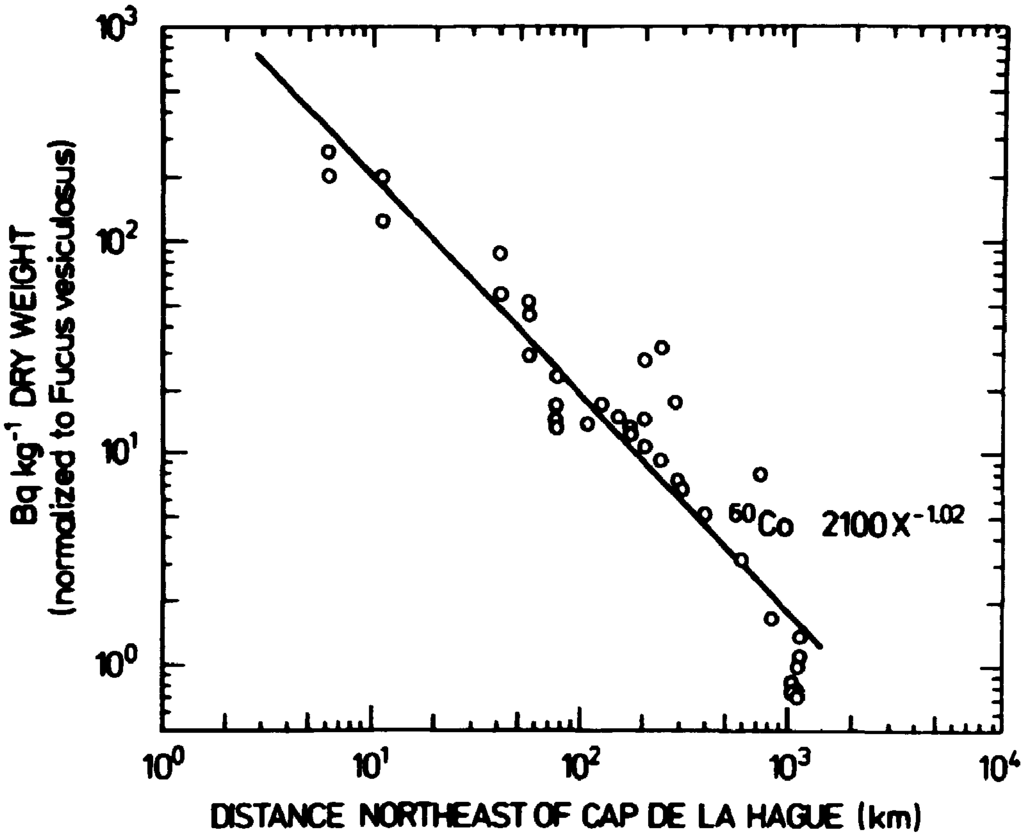


Fig. 4.3.2. The concentration of ^{60}Co in Fucus vesiculosus as a function of distance in km from La Hague in 1985.

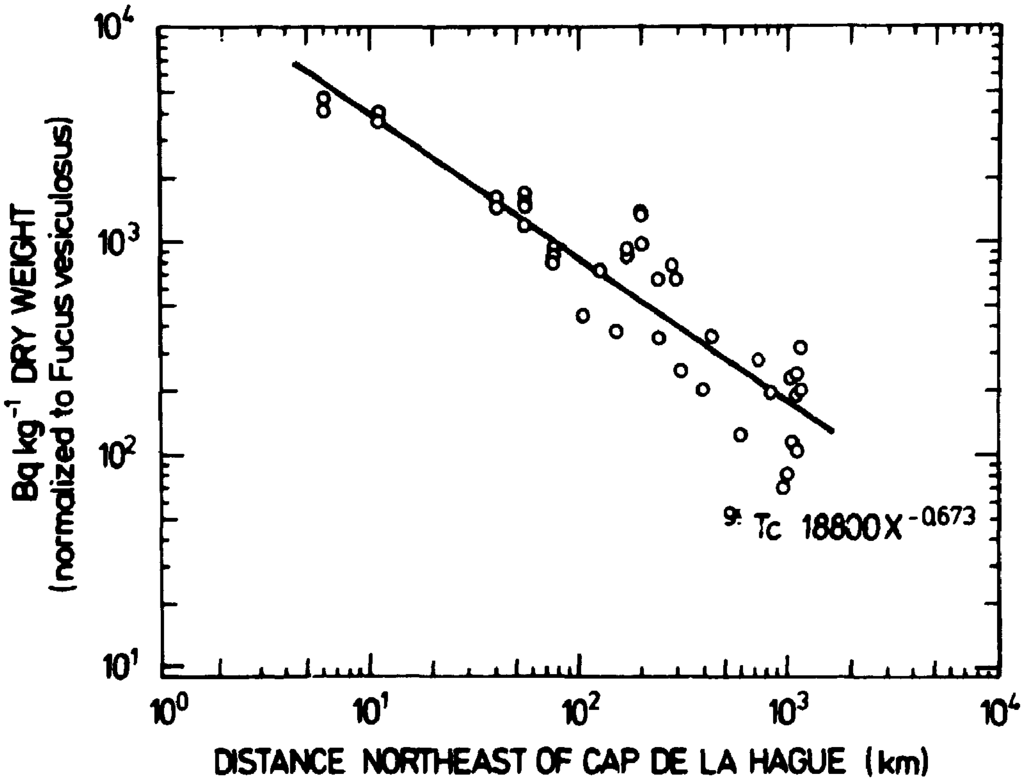


Fig. 4.3.3. The concentration of ^{99}Tc in Fucus vesiculosus as a function of distance in km from La Hague in 1985.

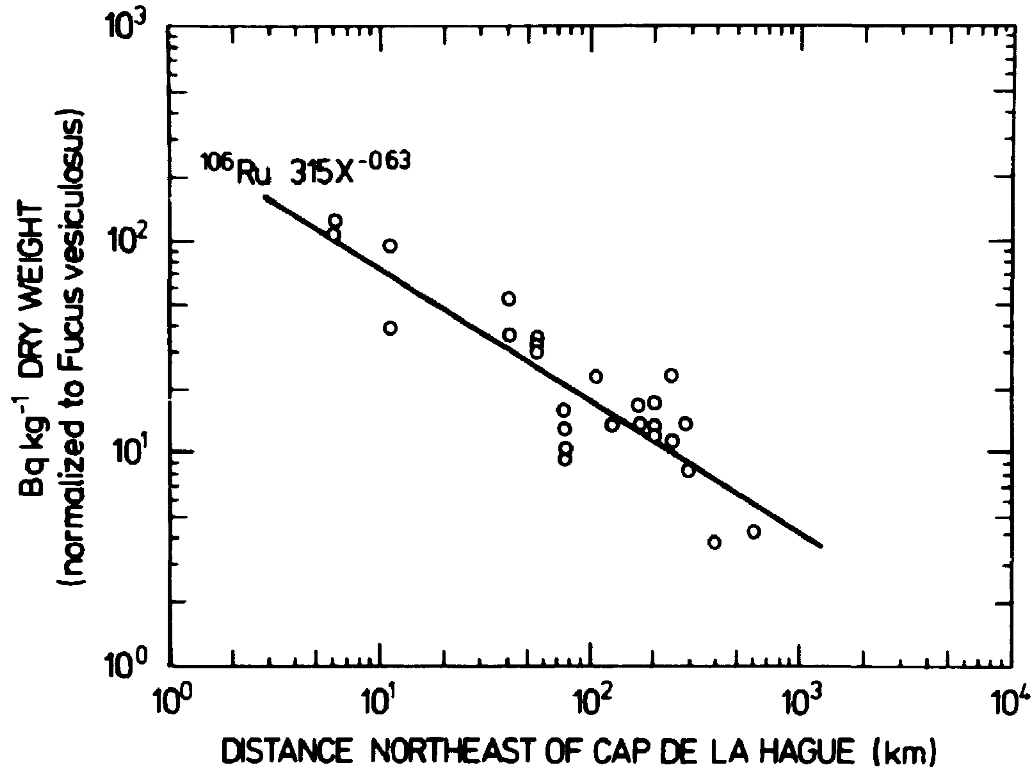


Fig. 4.3.4. The concentration of ^{106}Ru in Fucus vesiculosus as a function of distance in km from La Hague in 1985.

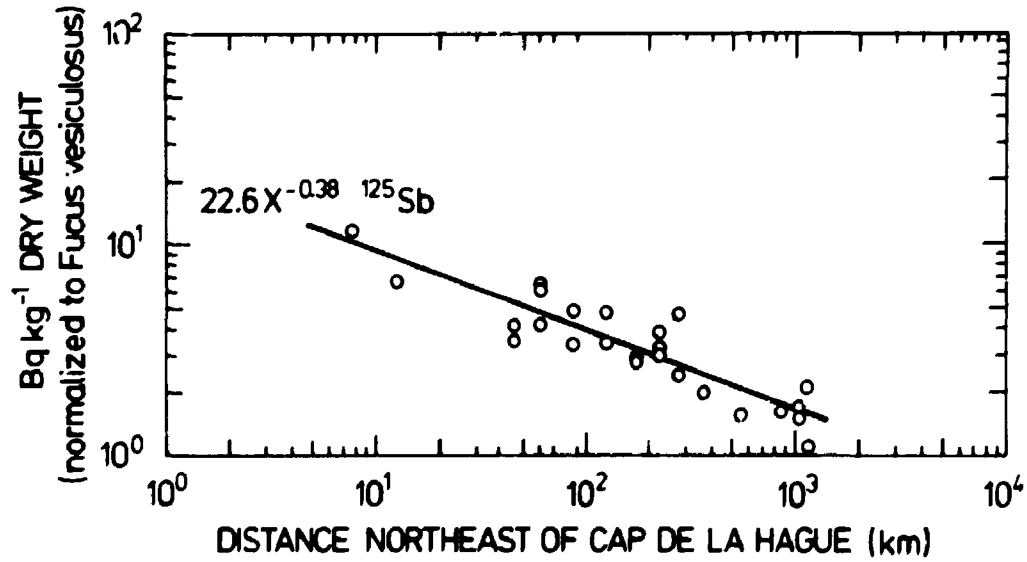


Fig. 4.3.5. The concentration of ^{125}Sb in Fucus vesiculosus as a function of distance in km from La Hague in 1985.

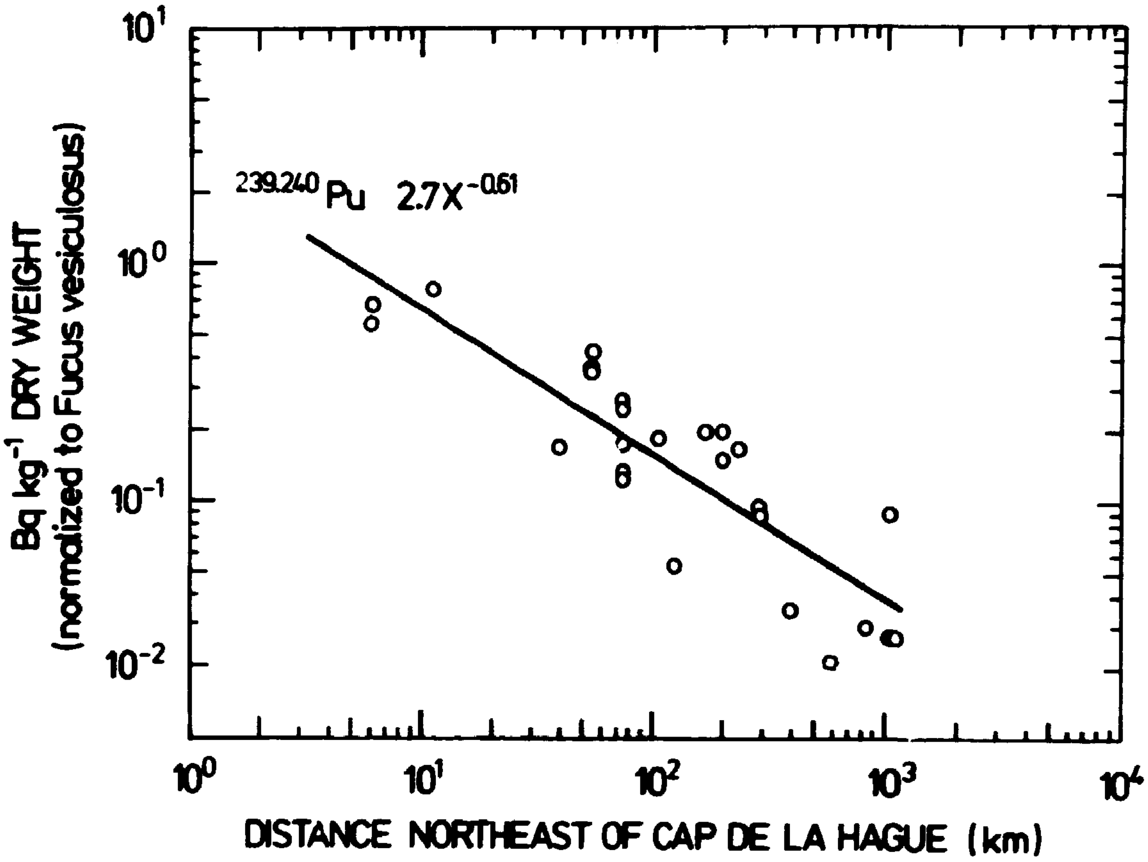


Fig. 4.3.6. The concentration of ^{238,240}Pu in Fucus vesiculosus as a function of distance in km from La Hague in 1985.

4.4. Various samples from the northern North Atlantic

4.4.1. Sea weed

A number of sea weed samples have been analysed for ^{99}Tc and a few other radionuclides (Table 4.4.1). The samples from the Iberian peninsula (Cascais and Vigo) are supposed to represent global fallout only. We have earlier shown that the ^{99}Tc concentrations in Fucus serratus and in Fucus spiralis are half of that in Fucus vesiculosus, and that Ascophyllum nodosum contains twice as much ^{99}Tc as Fucus vesiculosus. From this we conclude that the fallout background of ^{99}Tc in Fucus vesiculosus is about 1-1.5 Bq kg^{-1} dry weight. The sample from Grindavik in Iceland may thus also be considered to represent fallout of ^{99}Tc only. The $^{99}Tc/^{90}Sr$ ratios in the three samples mentioned above are, however, higher than what we would expect for global fallout in Fucus vesiculosus, where we in Greenland found a ratio of approximately only one[9]. Although we are dealing with other species, we do not think that this provides sufficient explanation for the discrepancy. We can thus not for the time being be completely sure whether the three samples actually represent fallout only.

At Cascais in Portugal a sea water sample was collected. It contained 4.2 Bq ^{137}Cs m^{-3}. From this we may calculate a concentration factor between Fucus spiralis and sea water of 150, which is in agreement with earlier observations[25].

4.4.2. Technetium-99 in surface sea water collected off West Greenland in 1984

At the CSS Baffin cruise to Thule in 1984 four large (~ 1 m^3) sea water samples were collected and the Tc was precipitated on board with $Fe(OH)_2$). We made double determinations at each of the two locations. The two duplicates were spiked with ^{97m}Tc tracer, in order to determine the yield.

The sample from Aug 3 was colected in Arctic water and the ^{99}Tc concentration is as expected higher in this sample due to a con-

Table 4.4.1. Technetium-99, ^{90}Sr and ^{137}Cs in seaweed samples from various locations in the northern North Atlantic. (Unit: Bq kg^{-1} dry weight)

Location	Species	Date	^{99}Tc	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{241}Am
Daneborg 74°19'N 20°15'W	Fu.	Aug 9, 1982	5.8				
Trondhjems Fjord 63°35'N 09°46'E	Fu.ve.	Aug 13, 1984	81		4.5		
- " -	Fu.se.	- " -	65		5.6		
Longyearby, Svalbard 78°13'N 15°40'E	Fu.di.	July 29, 1985	13.8				
Jersey 49°10'N 02°02'W	Fu.ve.	April 15, 1986	1080				
Trondhjems Fjord 63°35'N 09°46'E	Fu.ve.	Aug 19, 1985	47				
- " -	Fu.se.	- " -	47				
Cascais 38°42'N 09°25'W	Fu.sp.	May 10, 1985	0.56	0.21 A	0.63 A	0.080	0.021
Vigo 42°15'N 08°43'W	Fu.sp.	May 11, 1985	0.74	0.09 B	0.88 A	0.086 A	-
Grindavik 63°50'N 22°27'W	As.no.	Oct 10, 1985	2.3	0.20 A	0.22 A		

Fu.: Fucus disticus or vesiculosus; Fu.ve.: Fucus vesiculosus; Fu.di.: Fucus disticus; Fu.se.: Fucus serratus; Fu.sp.: Fucus spiralis; As.no.: Ascophyllum nodosum.

Table 4.4.2. Technetium-99 in surface sea water collected off West Greenland in August 1984

Location	Date	Temp. °C	Salinity o/oo	Bq ^{99}Tc m^{-3}
57°18'N 54°40'W	Aug 1	8.5	33.8	0.016±0.003
63°29'N 53°38'W	Aug 3	1.9	3?.0	0.045±0.017

The error term is 1 S.E. of double determinations.

stitution of Sellafield-derived ^{99}Tc. The observed concentration of ^{99}Tc off West Greenland is in good agreement with an expected transfer factor from Sellafield[9] in the order of 1 Bq m^{-3} per PBq yr^{-1}.

4.5. Studies of ^{90}Sr and ^{137}Cs in surface sea water collected off West Greenland by the Greenland Fisheries and Environmental Research Institute

The systematic sampling of sea water along the Greenland west coast, which began in 1983[4], was continued in 1985. The mean contents of ^{137}Cs were 4.7 Bq m^{-3} in the July as well as in the November sampling. This was the same mean as observed in the sampling in June-July 1984, but lower than the corresponding samples from November 1984. The ^{90}Sr concentrations were approximately 80% of those observed in 1984. Two low salinity samples from July 1985 (Table 4.5.1) contained relatively high ^{90}Sr concentrations (3.7 Bq m^{-3}). This is in agreement with observations made earlier[4]. The $^{137}Cs/^{90}Sr$ is in general higher than expected for global fallout. Minor amounts of ^{137}Cs from Sellafield in West Greenland waters are undoubtedly the reason for this observation. As in 1983 and 1984 the ^{137}Cs concentrations show a decreasing tendency from south to north. This is in particular evident for the stations closest to the coast.

Table 4.5.1. Strontium-90 and Cesium-137 in surface sea water off West Greenland in July 1985

Latitude N	Longitude W	Name of Location	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	Salinity o/oo
64°01'	52°19'	Fylla Bank (Nuuk)	2.9	5.3	32.3
63°58'	52°44'	- " -	-	6.1	33.0
63°55'	53°07'	- " -	3.0	6.0	32.0
63°53'	53°22'	- " -	-	5.4	33.6
63°48'	53°56'	- " -	2.1	4.2	34.2
65°06'	53°00'	Sukkertoppen (Maniitsoq)	3.0	5.0	33.5
65°06'	53°59'	- " -	-	5.3	33.4
65°06'	54°58'	- " -	2.4	5.1	33.7
66°53'	54°10'	Holsteinsborg (Sisimiut)	-	4.3	33.8
66°46'	55°36'	- " -	3.7	4.3	26.3
66°41'	56°38'	- " -	-	4.5	33.6
67°34'	57°10'	Intermediate Station	2.8	4.6	33.0
68°00'	55°00'	Egedesminde (Aasiaat)	-	4.2	33.9
68°04'	56°00'	- " -	2.4	4.5	33.5
68°08'	57°17'	- " -	-	4.1	33.4
68°14'	58°40'	- " -	3.7	3.9	31.9
68°43'	55°03'	Disko rende	-	4.6	33.9
69°42'	51°38'	Arveprinsen	2.4	3.6	33.1
68°55'	52°24'	Skansen-Akunaq	-	3.7	33.2

Table 4.5.2. Strontium-90 and Cesium-137 in surface sea water off West Greenland in November 1985

Latitude N	Longitude W	Name of Location	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	Salinity o/oo
64°01'	52°19'	Fylla Bank (Nuuk)	2.9	5.7	33.0
63°55'	53°07'	- " -	2.5	4.0	33.7
63°48'	53°56'	- " -	2.6	4.1	33.8
65°06'	53°00'	Sukkertoppen (Maniitsoq)	2.7	5.9	33.3
65°06'	53°59'	- " -	2.8	5.2	33.3
65°06'	54°58'	- " -	2.6	4.4	33.9
66°53'	54°10'	Holsteinsborg (Sisimiut)	2.8	5.2	33.0
66°46'	55°36'	- " -	2.8	5.0	33.0
66°41'	56°38'	- " -	2.7	4.4	33.1
67°34'	57°10'	Intermediate Station	3.6	4.5	32.7
68°00'	55°00'	Egedesminde (Aasiaat)	3.0	4.7	32.9
68°04'	56°00'	- " -	2.6	4.3	32.8
68°08'	57°17'	- " -	2.7	4.6	32.7
68°43'	55°03'	Disko rende	3.0	4.7	32.7
69°08'	58°24'	- " -	3.2	4.8	32.7
69°30'	58°20'	Disko Fjord	3.0	4.4	32.7
70°34'	54°47'	Hare Ø North	2.4	3.9	33.2
68°55'	52°24'	Skansen-Akunaq	3.2	4.5	32.6

Table 4.5.3. Analysis of variance of ln Bq ^{90}Sr m^{-3} surface sea water off West Greenland in July and November 1983, 1984, and 1985

Variation	SSD	f	s^2	v^2	P
Between locations	0.563	29	0.019	0.778	-
Between months	1.224	5	0.245	9.809	>99.95%
Month × loc.	1.447	58	0.025	0.790	-
Remainder	0.063	2	0.032		

Table 4.5.4. Analysis of variance of ln Bq ^{137}Cs m^{-3} surface sea water off West Greenland in July and November 1983, 1984, and 1985

Variation	SSD	f	s^2	v^2	P
Between locations	1.170	30	0.039	3.052	>99.95%
Between months	0.623	5	0.125	9.748	>99.95%
Month × loc.	0.844	66	0.013	1.140	-
Remainder	0.022	2	0.011		

ACKNOWLEDGEMENTS

The authors wish to thank Anna Holm Pedersen, Else Marie Sørensen, Jytte Clausen, Anna Madsen, Karen Wie Nielsen, Elise Ebling, Oda Brandstrup, Alice Kjølhede, Helle Porsdal, and Karen Mandrup Jensen for their conscientious performance of the analyses.

Our thanks are furthermore due the Institute of Hygiene in Thorshavn, to the district physicians in Greenland and the telestations, GTO and all other persons and institutions in the Faroe Islands, Greenland and Denmark who have contributed by collecting samples.

The Alfred Wegener Institute for Polar Research, Bremerhaven, are acknowledged for their kind invitations to participate in the cruise with the R.V. "Polarstern" in 1985.

Martin Munch Hansen the Greenland Fisheries and Environmental Research Institute kindly provided us with sea weed samples from Greenland.

The present study was partly sponsored by the C.E.C. Radiation Protection Research Programme.

We finally thank the Commission for Scientific Research in Greenland for permission to collect samples in Greenland.

REFERENCES

1) Environmental Radioactivity in the Faroes 1962-1982. Risø Reports Nos. 64, 86, 108, 131, 155, 181, 202, 221, 246, 266, 292, 306, 324, 346, 362, 387, 404, 422, 448, 470 and 488 (1963-1983).

2) Environmental Radioactivity in Greenland 1962-1982. Risø Reports Nos. 65, 87, 109, 132, 155, 182, 203, 222, 247, 267, 293, 307, 325, 347, 363, 388, 405, 423, 448, 471 and 489 (1963-1983).

3) A. Aarkrog, S. Boelskifte, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen, and S.P. Nielsen, Environmental Radioactivity in Denmark in 1985. Risø Report No. 540 (1986).

4) Environmental Radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included. 1983-1984. Risø Reports Nos. 510 and 528 (1984-1985).

5) A. Aarkrog, Environmental Studies on Radioecological Sensitivity and Variability. Risø-R-437 (June 1979).

6) A. Aarkrog, H. Dahlgaard, H. Hansen, E. Holm, L. Hallstadius, J. Rioseco and G. Christensen. Radioactive Tracer Studies in the Surface Waters of the northern North Atlantic including the Greenland, Norwegian and Barents Seas. Proceedings from a Nordic Symposium on Chemical Tracers for Studying Water Masses and Physical Processes in the Sea in Reykjavik Aug 28-Sept 1, 1984. RIT FISKIDEILDAR 9. 37-42 (1985).

9) A. Aarkrog, S. Boelskifte, H. Dahlgaard, S. Duniec, L. Hallstadius, E. Holm and J.N. Smith. Technetium-99 and Cesium-134 as long distance tracers in Arctic waters. Estuarine, Coastal and Shelf Science 24, 637-647 (1987).

11) A. Aarkrog, H. Dahlgaard, L. Hallstadius, H. Hansen, and E. Holm. Radiocesium from Sellafield Effluents in Greenland Waters. Nature 304, p. 49-51 (1983).

12) R.S. Cambray. Annual discharges of certain long-lived radionuclides to the sea and to the atmosphere from the Sellafield works, Cumbria 1957-1981. AERE-M 3269 (1982).

13) BNFL 1978-1985. Annual Report on Radioactive Discharge and Monitoring of the Environment. British Nuclear Fuels Limited, Risley, Warrington, Cheshire, U.K.

21) A. Aarkrog. Risk Assessment of long-lived radionuclides in the marine environment. Invited paper to International Symposium on the behavior of long-lived radionuclides in the marine environment. La Specia, 28-30 Sept. 1983, p. 419-442.

23) H. Kautsky, Deutschen Hydrographischen Zeitschrift 26, 242-246 (1973).

24) A. Aarkrog, H. Dahlgaard, S. Duniec, P. Guequeniat, and E. Holm. The application of sea weeds as bioindicators for radioactive pollution in the Channel and southern North Sea. To be published in the proceedings from International Symposium on radioactivity and oceanography, June 1-5, 1987, Cherbourg.

25) A. Aarkrog (editor). Bioindicator studies in Nordic waters. Risø-M-2517 (1985).

Title and author(s)

ENVIRONMENTAL RADIOACTIVITY IN THE NORTH ATLANTIC REGION. THE FAROE ISLANDS AND GREENLAND INCLUDED. 1985

A. Aarkrog, S. Boelskifte, E. Buch°, G.C. Christensen*, H. Dahlgaard, L. Hallstadius**, H. Hansen, E. Holm***, and J. Rioseco**

o The Greenland Fisheries and Environmental Research Institute, Denmark
* Institute for Energy Technology, Kjeller, Norway
** University of Lund, Sweden
*** International Laboratory of Marine Radioactivity, Monaco

Date June 1987

Department or group Health Physics

Groups own registration number(s)

Project/contract no.

Pages 83 **Tables** 48 **Illustrations** 32 **References** 14

ISBN 87-550-1342-2

Abstract (Max. 2000 char.)

Measurements of fallout radioactivity in the North Atlantic region including the Faroe Islands and Greenland are reported. Strontium-90 and cesium-137 was determined in samples of precipitation, sea water, vegetation, various foodstuffs (including milk in the Faroes) and drinking water. Estimates are given of the mean contents of ^{90}Sr and ^{137}Cs in human diet in the Faroes and Greenland in 1985. Results from samplings of surface sea water and seaweed in the English Channel, the Fram Strait and along the Norwegian and Greenland coasts are reported. Beside radiocesium and ^{90}Sr some of these samples have also been analysed for tritium, plutonium and americium. Finally technetium-99 data on seaweed and sea water samples collected in the North Atlantic region are presented.

Descriptors - INIS

AMERICIUM 241; ANIMALS; ATMOSPHERIC PRECIPITATIONS; BONE TISSUES; CESIUM 134; CESIUM 137; COASTAL WATERS; DIET; DRINKING WATER; ENVIRONMENT; FAROE ISLANDS; FOOD CHAINS; GLOBAL FALLOUT; GREENLAND; MAN; MILK; MOLLUSCS; NORWAY; PLANTS; PLUTONIUM 238; PLUTONIUM 239; RADIOACTIVITY; SEAWATER; SEAWEEDS; SEDIMENTS; SHRIMP; STRONTIUM 90; TECHNETIUM 99; UNITED KINGDOM

Sales distributors:
G.E.C. Gad Strøget
Vimmelskaftet 32
DK-1161 Copenhagen K, Denmark

Available on exchange from:
Risø Library, Risø National Laboratory,
P.O.Box 49, DK-4000 Roskilde, Denmark

ISBN 87-550-1342-2
ISSN 0106-2840
ISSN 0900-8098